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Air/Superfund National Technical Guidance Study Series, Volume 3 Estimation of Air Emissions from Cleanup Activities at Superfund Sites

Radian Corp., Austin, TX

Prepared for

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Abstract: The manual was developed concurrently with three related manuals that also address air issues arising from hazardous waste sites. The overall goal of the program is to develop guidelines for predicting and/or measuring air emissions during remedial activities. For the preliminary version of the manual, the objectives were to: Present a protocol for estimating air emissions from remedial activities at NPL sites; Identify existing data gaps or limitations in the protocol; Provide guidance for collecting data to estimate or confirm air emissions. Field studies are scheduled to address one of the data gaps that has been identified. A revised version of the manual will be published subsequent to the research.

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Volume III - Estimation of Air Emissions from Cleanup Activities at Superfund Sites

Interim Final

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VOLUME III

ESTIMATION OF AIR EMISSIONS
FROM CLEAN-UP ACTIVITIES
AT SUPERFUND SITES

INTERIM FINAL

by

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PREFACE

This is one in a series of manuals dealing with air pathway analysis at hazardous waste sites. This document was developed for the Office of Air Quality Planning and Standards in cooperation with the Office of Emergency and Remedial Response (Superfund). It has been reviewed by the National Technical Guidance Study Technical Advisory Committee and an expanded review group consisting of State agencies, various groups within the U.S. Environmental Protection Agency, and the private sector. This document is an interim final manual offering technical guidance for use by a diverse audience including EPA Air and Superfund Regional and Headquarters staff, State Air and Superfund program staff, Federal and State remedial and removal contractors, and potentially responsible parties in analyzing air pathways at hazardous waste sites. This manual is written to serve the needs of individuals having different levels of scientific training and experience in designing, conducting, and reviewing air pathway analyses. Because assumptions and judgments are required in many parts of the analysis, the individuals conducting air pathway analyses need a strong technical background in air emission measurements, modeling, and monitoring. Remedial Project Managers, On Scene Coordinators, and the Regional Air program staff, supported by the technical expertise of their contractors, will use this guide when establishing data quality objectives and the appropriate scientific approach to air pathway analysis. This manual provides for flexibility in tailoring the air pathway analysis to the specific conditions of each site, the relative risk posed by this and other pathways, and the program resource constraints.

Air pathway analyses cannot be reduced to simple "cookbook" procedures. Therefore, the manual is designed to be flexible, allowing use of professional judgment. The procedures set out in this manual are intended solely for technical guidance. These procedures are not intended, nor can they be relied upon, to create rights substantive or procedural, enforceable by any party in litigation with the United States.

It is envisioned that this manual will be periodically updated to incorporate new data and information on air pathway analysis procedures. The Agency reserves the right to act at variance with these procedures and to change them as new information and technical tools become available on air pathway analyses without formal public notice. The Agency will, however, attempt to make any revised or updated manual available to those who currently have a copy through the registration form included with the manual.

Copies of this report are available, as supplies permit, through the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711 or from the National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161.

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SUPERFUND ABBREVIATIONS/ACRONYMS

ACGIH	American Conference of Government Industrial Hygienists
ACL	Alternate Concentration Limit
AO	Administrative Order on Consent
APA	Air Pathway Analysis
APCD	Air Pollution Control Device
ARAR	Applicable or Relevant and Appropriate Requirement (Cleanup Standard)
ATSDR	Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
CAS	Carbon Adsorption System
CD	Consent Decree
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CERI	Center for Environmental Research Information
CR	Community Relations
CRF	Combustion Research Facility--Pine Bluff, Arkansas
CFR	Code of Federal Regulations
CWA	Clean Water Act
DQO	Data Quality Objective
DRE	Destruction and Removal Efficiency
EDD	Enforcement Decision Document
ERT	Environmental Response Team
ESP	Electrostatic Precipitator
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FP	Fine Particulate
FS	Feasibility Study
HRS	Hazard Ranking System
HSWA	Hazardous Waste Engineering Amendments to RCRA, 1984
HWERL	Hazardous Waste Engineering Research Laboratory
IDLH	Immediately Dangerous to Life or Health
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
NBAR	Nonbinding Preliminary Allocation of Responsibility
NCP	National Contingency Plan
NEIC	National Enforcement Investigations Center
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health
NPL	National Priorities List
NRC	National Response Center
NRT	National Response Team
NTIS	National Technical Information Service
OERR	Office of Emergency and Remedial Response
O&M	Operation and Maintenance
ORD	Office of Research and Development
OSC	On-Scene Coordinator
OSH Act	Occupational Safety and Health Act
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OTA	Office of Technology Assessment
PA	Preliminary Assessment

PEL	Permissible Exposure Limits
PIC	Products of Incomplete Combustion
PM-20	Particulate Matter with Physical Diameter <20 um
PRP	Potentially Responsible Party
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RA	Remedial Action
RCRA	Resource Conversation and Recovery Act
RD	Remedial Design
REL	Recommended Exposure Limit
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RPM	Remedial Project Manager
RRT	Regional Response Team
RQ	Reportable Quantity
SAB	Science Advisory Board
SARA	Superfund Amendments and Reauthorization Act
SCAP	Superfund Comprehensive Accomplishments Plan
SI	Site Inspection
SITE	Superfund Innovative Technology Evaluation
SWDA	Solid Waste Disposal Act (RCRA predecessor)
TLV	Threshold Limit Value
TLV-C	Threshold Limit Value - Ceiling
TLV-STEL	Threshold Limit Value - Short-Term Exposure Limit
TLV-TWA	Threshold Limit Value - Time-Weighted Average
TSDF	Treatment Storage and Disposal Facility
TSCA	Toxic Substances Control Act
TSP	Total Suspended Particulate
Title III	Emergency Planning and Community Right-to-Know Act (SARA)
T&E	Testing and Evaluation
UST	Underground Storage Tank
VO	Volatile Organics
VOC	Volatile Organic Compound

KEY TO PARAMETERS USED IN EQUATIONS

Parameter	Definition	Units
A	Cross-sectional or surface area	m^2
Ash	Ash content of waste feed	g/kg
CE	Control efficiency	%
C_i	Concentration of species i	ug/L or g/kg or g/m^3
C_i, in	C_i of influent stream	
C_i, out	C_i of effluent stream	
DRE	Destruction and removal efficiency	%
d	Drop height	m
d_a	Densit of air	g/m^3
EF_i	Emission factor for species i	kg/hr or kg/unit operation
ER_i	Emission rate of species i	g/sec or $g/m^2 \cdot sec$
E_i	Emissions of species i	kg
g	Acceleration due to gravity	m/sec^2
h	Vertical distance	m
I	Industrial augmentation factor	-
id	Inside diameter	m
k	Particle size multiplier	-
k_a	Air permeability in soil	m/sec
L	Surface dust loading	kg/km
l	Distance	m
LP_r	Liquid product recovery rate	L/sec
M	Moisture content	Wt. %
%MF	Metal emitted as % of metal fed	%
m_w	Mass flow rate of waste	kg/sec
n_a	Viscosity of air	$N \cdot sec/m^2$
n	Number of traffic lanes	-
P	Pressure	N/m^2
$^{P}H_2O$	Pressure	m of H_2O

KEY TO PARAMETERS USED IN EQUATIONS (Continued)

Parameter	Definition	Units
^{PM}Quench	Solids produced by quenching	kg/hr
^{PM}Drop	Solids resulting from droplet carryover	kg/hr
Q	Flow rate	m^3/min
p	Number of days/year with precipitation	days
RE	Removal efficiency	%
RT	Retention time	sec
S	Mean vehicle speed	km/hr
s	Silt content	Wt. %
sL	Silt loading of road surface	g/m^2
T	Temperature	°C
t_x	Number of days that remedial option X is performed	days
U	Mean wind speed	m/sec
V	Volume	m^3
VKT	Vehicle kilometer traveled	km
v	Velocity	m/sec
W	Mean vehicle weight	Mg
WC_i	Weight fraction of component i in process stream	kg/kg
x	Mean number of wheels	-
X,Y,Z	Generic remedial options	-

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The United States Environmental Protection Agency (EPA) is responsible for the assessment and cleanup of National Priority List (NPL) sites, under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA). CERCLA created a tax on the chemical and petroleum industries. The money collected from the tax goes to a Trust Fund (commonly referred to as the Superfund) to clean up abandoned or uncontrolled hazardous waste sites.

The law authorizes the EPA to implement two types of response actions:

- Short-term removal actions to quickly address actual or threatened releases requiring expedited response; and
- Longer term remedial actions that end or reduce the actual or threatened releases of hazardous substances that are serious, but not immediately life-threatening.

The response actions may include removal to a licensed hazardous waste facility, permanent containment of the waste, on-site destruction or treatment, or removal of the source of ground-water contamination while halting further transport of the contaminants.

The primary motivations for clean-up of NPL sites are to protect the general environment and to protect the health and safety of persons in proximity to the site. Contamination at a given NPL site may pose a current or future risk by exposure from a number of potential pathways. These include direct contact with the in-situ pollutants, subsurface migration of the contaminants via vapor plumes or ground-water plumes, contamination of surface waters, and atmospheric transport (and deposition) of gaseous, aerosolized, or wind-blown contaminants. To successfully assess and clean up an NPL site, it is necessary to characterize the initial state of the site and to analyze the potential effects of pollutant transport via the applicable exposure pathways for each step of the assessment and clean-up process. The EPA is developing a four-volume set of guidance manuals to assist the RPM in assessing air impacts throughout the Superfund process. This manual (Volume III) provides guidance for estimating the impact of contaminant migration from one pathway, the air pathway, during remediation, a key step of the overall process.

In addition to the federal program for the cleanup of hazardous waste sites, most states have implemented similar programs and many private parties are also initiating cleanups of hazardous waste sites. Although the terminology in this manual tends to refelct the structure and approaches of the federal program, the information in this manual should also be applicable to the cleanup of any kind of site with hazardous wastes or hazardous substances.

Emissions of organic and inorganic contaminants from hazardous waste sites may pose a potential risk, even from undisturbed sites. Clean-up activities have the potential to greatly increase undisturbed or baseline emissions and may result in significant impacts to the local air quality for both on-site workers and the surrounding community. However, the air quality impacts of clean-up methods such as soil removal, incineration, air stripping and soil vapor extraction have not been fully characterized. Therefore, the air pathway has historically been difficult to assess for remedial actions.

This manual is a preliminary step in meeting the EPA's stated needs to:

- Establish the range of clean-up operations that can lead to significant air emissions;
- Determine what emissions estimation techniques are available;

- Establish emissions relationships based on ambient air monitoring data; and

- Develop a uniform assessment technique for performing air pathway analyses (APA).

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1.2 OBJECTIVES

The overall goal of this program is to develop guidelines for predicting and/or measuring air emissions during remedial activities. For this preliminary version of the manual, the objectives were to:

1) Present a protocol for estimating air emissions from remedial activities at NPL sites;

2) Identify existing data gaps or limitations in the protocol; and

3) Provide guidance for collecting data to estimate or confirm air emissions.

Field studies are scheduled to address one of the data gaps that has been identified. A revised version of this manual will be published subsequent to this research.

1.3 APPROACH

To meet the objectives of this program, three steps were undertaken to compile and assess existing information: 1) Conduct a literature search, 2) Perform a survey of key researchers, and 3) Review and evaluate the collected information. This work served as the basis for developing the protocol for estimating air emission factors for remediation presented herein. Each step of the approach is discussed below.

A computer-assisted search of 15 databases was performed to identify published literature of potential interest. Keywords were formulated into a search strategy to identify abstracts related to both baseline and remedial emissions. Approximately 1400 abstracts were reviewed, and over one hundred publications were identified as pertinent and obtained by staff librarians.

The literature search was augmented by a telephone survey to locate and access unpublished data or research in progress. A list of contacts was developed that included regional EPA personnel, employees of EPA research offices, EPA contractors, university researchers, and referrals from those initially contacted. A set of questionnaires was used to put the responses obtained during the phone survey in a standard format.

The collected data were reviewed and evaluated with respect to the following:

- Which remedial operations have significant potential air emissions;
- What parameters influence air emissions;
- What relationship exists between emissions and waste concentration and composition;
- What types of monitoring data are available: and
- What data gaps still exist.

The information was then used to develop emission relationships for use in the protocol development.

1.4 RECOMMENDED USES OF THIS MANUAL

This manual is, to the extent possible, a complete, stand-alone document. It is, however, intended to complement existing guidance manuals for the Superfund program. This manual (Volume III) was developed concurrently with three related manuals that also address air issues arising

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from hazardous waste sites. The first manual (1) presents more generalized guidance for addressing air issues throughout the clean-up process depicted in Figure 1. The second manual (2) presents guidelines for developing baseline emission factors for NPL sites prior to remediation. The fourth manual (3) presents guidance for air monitoring and modeling at NPL sites. Together, these four manuals provide a complete treatment of air issues for Superfund applications.

The steps in the NPL site clean-up process, from site discovery to remediation and subsequent operation and maintenance, are shown in Figure 1. Volume III may be useful at several steps for assessing potential air impacts from site remediation; these steps are labeled in the figure by "Air" and an input arrow.

The primary intended use for this manual (Volume III) is for estimating air impacts as part of the evaluation of alternative remedial options (e.g., incineration versus ground-water stripping versus removal, etc.). Therefore, the manual's guidance is input to the record of decision (ROD) step, as well as the RI/FS and remedial design (RD) steps. A second use of the manual is for estimating emissions once a specific remedial action (RA) or removal plan has been selected. The manual can be used to estimate the air impact from altering the rate of clean-up or changing some other key engineering parameter for a given remedial technology. This manual also provides several secondary functions, including guidance on control technologies and an introduction to collecting input (monitoring and modeling) data.

Furthermore, this manual provides the important function of standardizing the air pathway analysis (APA) for remediation of NPL sites, thereby ensuring that a uniform and systematic approach is followed for the diverse universe of NPL sites. The manual provides a step-by-step protocol for estimating air quality impacts resulting from site mitigation. For each step, a three-tiered approach is presented. The approaches in order of preference are:

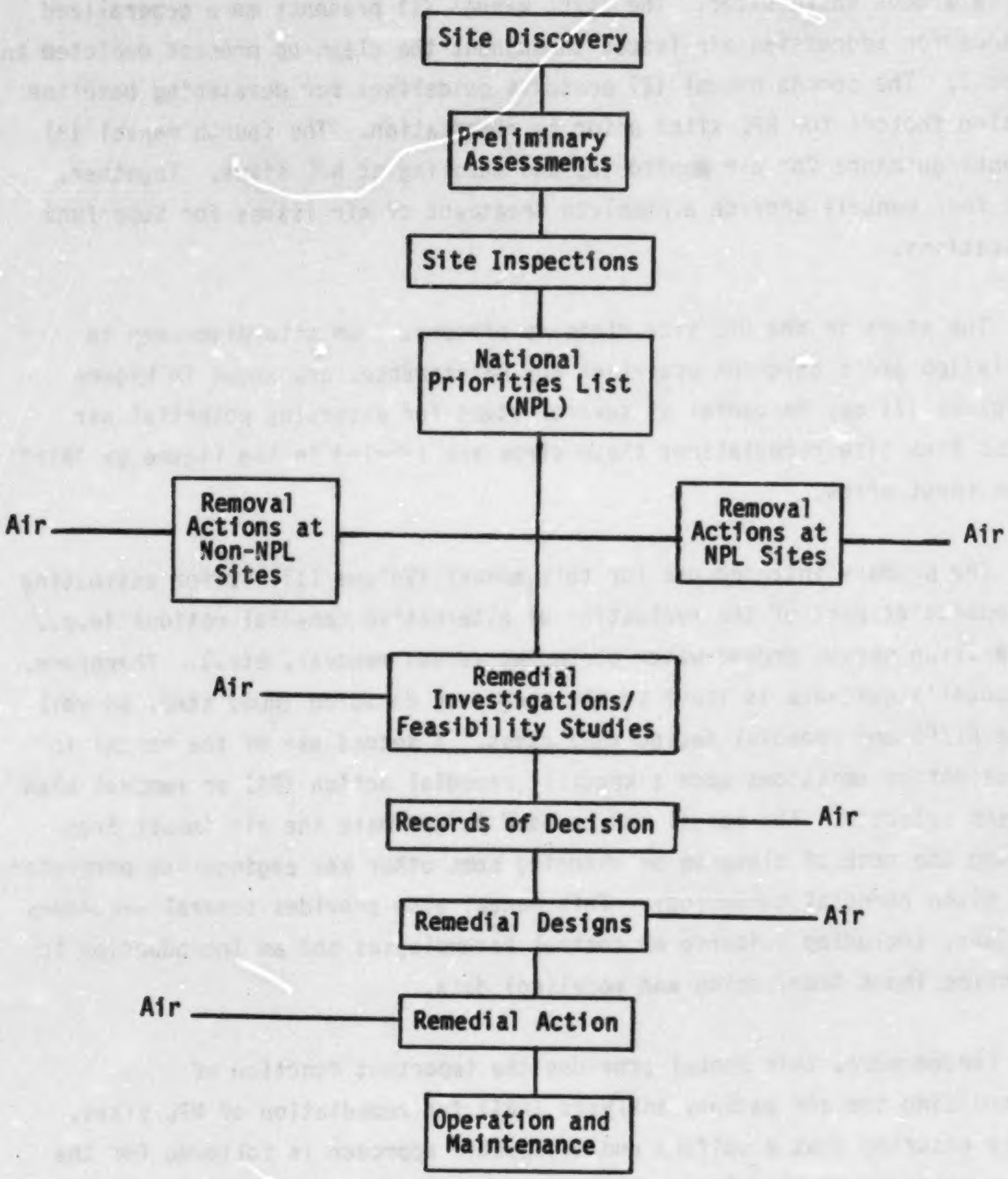

Site Discovery
Preliminary Assessments
Site Inspections
National Priorities List (NPL)
Air
Removal Actions at Non-NPL Sites
Removal Actions at NPL Sites
Air
Air
Remedial Investigations/ Feasibility Studies
Records of Decision
Air
Remedial Designs
Air
Air
Remedial Action
Operation and Maintenance

Figure 1. Superfund flow chart, noting elements where this manual may apply.

1) Use of site-specific field data;

2) Use of predictive contaminant transport models using site-specific inputs;

3) Use of tabulated default values when site-specific information is unavailable.

Therefore, emissions can be estimated regardless of the state of knowledge regarding a given site. Of course, the confidence of the emissions estimates depends on the associated confidence of the inputs to the estimation procedure.

Limitations of the emissions estimation procedures should be borne in mind. The primary limitation is that the data quality of any emissions estimate is dependent on the data quality of the inputs and on the quality of the assumptions that are made. The use of site-specific data as input to the estimation procedure is preferable to the use of predictive models, which in turn are preferable to the use of tabulated generic emission factors. Data of known quality (confidence) should be used whenever available. In many cases, the conceptual site model will be developed from a limited database. The resulting estimates of volume of contaminated material, the type of contaminants present, the concentration of the contaminants, etc. will have large associated uncertainties. Therefore, any emissions derived from such data will have an even larger overall uncertainty.

In addition, the estimation procedure has its own inherent limitations. The predictive equations and typical values given in the succeeding sections for each remedial technology were designed to be applicable to as wide a range of sites as possible. They are most applicable for the "typical" use of a given technology at a "typical" site. Atypical site characteristics such as permafrost, high ground-water table, naturally immobilized waste, impeded air dispersion routes, etc. or atypical remedial technologies or other applications may affect the validity of the emission estimation procedure.

Similarly, the step of the overall protocol--estimate concentration at the receptors--has inherent limitations. Dispersion models do not work well for estimating dispersion over very short distances (i.e., much closer than 100 meters). Finally, the action levels selected for the receptors of interest are themselves extremely arbitrary. Exposure standards are still evolving and even at their best only address the exposure for an average person. Persons with respiratory or other problems may be adversely affected by concentrations of pollutants well below any established standards.

1.5 DOCUMENT ORGANIZATION

There are five remaining sections to Volume III. Section 2 is a discussion of emission processes during remedial operations. Section 3 presents detailed procedures for estimating air emissions during remediation. A protocol for estimating emissions is first presented and discussed, then specific inputs for each applicable remedial technology are given. A hypothetical case study is given in Section 4 to demonstrate the use of the manual. An introduction to monitoring, modeling, and data quality issues is given in Section 5 for users of the manual requiring additional input data for the protocol. Section 6 lists the references cited in the manual.

Ancillary information is given as appendices to this manual. Appendix A is an annotated bibliography for the documents reviewed during the protocol development. A glossary of terms is given as Appendix B. Appendix C presents the relative advantages and disadvantages of various incineration technologies. A brief discussion of the steps in the overall protocol for estimating air quality impacts from emissions is given in Appendix D.

SECTION 2

DISCUSSION OF EMISSIONS DURING SITE CLEANUPS

This section is intended to provide the user with sufficient background information regarding remedial technologies to use the estimation procedures presented in Section 3. The section addresses potential emission sources. Potential air quality impacts and receptors of concern are discussed in Volume IV (3). Users should consult the references cited in this section and those listed in the bibliography (Appendix A) for further background material.

Potential emission sources include point sources such as incineration, air stripping of ground water, and in-situ soil venting; and area sources such as soils handling and fixation/stabilization. The discussion of each remedial technology covers sources, key parameters affecting emissions, and possible control technologies.

Remedial technology point sources are first addressed, followed by remedial technologies categorized as area sources.

2.1 THERMAL DESTRUCTION

The following section describes emission processes from thermal destruction. Thermal destruction includes a number of processes with incineration being the most widely studied and used.

As applicable or relevant and appropriate requirements (ARARs), several of the requirements under the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA) will also be applied to the thermal destruction of wastes from NPL sites. Most notably, RCRA requires 99.99% destruction and removal of regulated organic wastes. Similarly, TSCA governs wastes containing PCBs and dioxins and requires 99.9999% destruction and removal efficiency. Regulations under these Acts also generally require trial burns to demonstrate the achievement of these and other related requirements. Assuming these requirements under RCRA or TSCA are also taken as requirements for thermal destruction of an NPL site's wastes, this obviously simplifies the estimation of the maximum emissions from that site. The main value of this manual would thus be: 1) to estimate emissions for pollutants (such as products of incomplete combustion) not directly covered by RCRA or TSCA regulations, 2) to evaluate whether incinerator designs are likely to achieve desired emissions controls, and 3) to estimate emissions for cases when RCRA and TSCA requirements are judged to be neither applicable nor appropriate. This section also provides discussion of types of thermal destruction devices, types of pollutants emitted, tpyes of control devices, and considerations in applying thermal destruction technologies.

2.1.1 Emission Sources

Thermal destruction of hazardous waste is an engineered process in which controlled combustion is used to decompose the chemical structures of organic compounds thereby substantially reducing the volume and toxicity of the hazardous components of the waste. The physical forms of wastes which can be destroyed by thermal destruction include gases, liquids, solids, and sludges. Thermal destruction is usually a cost-effective remedial option for highly toxic organic wastes and for those organic wastes having a large inherent heating value.

While thermal destruction has long been seen as a viable and effective means of hazardous waste disposal, changes in the environmental issues, economics, and regulatory climate surrounding waste management technologies have caused thermal destruction to become recognized as one of the best demonstrated and available methods of waste destruction. CERCLA favors treatment over removal, and on-site waste treatment over off-site; existing thermal destruction technologies can fulfill these goals for many types of sites.

A variety of effective thermal destruction technologies are available and the selection of an appropriate system requires an understanding of the chemical, physical, and thermodynamic properties of the waste to be destroyed. The major existing and emerging thermal destruction technologies are listed in Table 1.

Liquid injection incinerators are typically refractory lined cylinders in which pumpable liquids as well as gases are burned. Rotary kiln units are also refractory lined cylinders, but they are mounted at slight incline from the horizontal plane. These units are suitable for destroying solids, sludges, containerized wastes, and liquids. Rotation of the kiln moves the waste through the kiln and simultaneously provides good mixing of the waste. To achieve high waste destruction, a rotary kiln unit usually employs a secondary combustion chamber or afterburner. The afterburner is essentially a gas incinerator which burns the residual wastes contained in the rotary kiln exhaust gas. Cement kilns are large-scale rotary kilns which are used for the commercial production of cement. The cement kiln provides the high temperatures and extended residence times required for waste destruction. Industrial boilers are another example of a commercial process in which many hazardous materials may be economically destroyed. In boilers, the waste (usually a liquid) is typically injected with an auxiliary fuel through the unit's burner nozzles.

In infrared incineration, wastes are moved through the primary combustion chamber on a steel belt and electrically powered, silicon carbide rods mounted along the chamber walls provide the necessary heat. Off-gas from the primary chamber enters the secondary chamber or afterburner, which contains a gas-fired burner to ignite the combustible gases. Infrared heating elements may also beused in the after-burner.

Hearth incinerators (also called controlled, starved air, or pyrolytic incinerators) also employ a two stage combustion process. In these units, waste is ram fed into the primary combustion chamber and burned under starved air conditions (pyrolysis). The resulting combustion gases containing

TABLE 1. THERMAL DESTRUCTION TECHNOLOGIES

Incineration Technologies:

Liquid Injection
Rotary Kiln
Cement Kiln
Boilers
Multiple Hearth
Infrared
Fluidized-bed
At-Sea

Emerging Thermal Destruction Technologies:

Molten Matrix
High-Temperature Fluid Wall
Plasma Arc
Super-Critical Water

Sources: References 4 and 5

primarily volatilized hydrocarbons, carbon monoxide, and partially combusted hydrocarbons pass into the secondary combustion chamber where excess air and sometimes fuel are added to ensure complete combustion.

The last major type of incineration system is the fluidized bed incinerator. Fluidized bed units are used primarily for burning liquids, sludges, and finely shredded (<1 in. x 1 in.) solid materials. They are refractory lined vessels which contain particles of sand, alumina, calcium carbonate, or other fluidizing material. Combustion air is introduced through distributors in the floor of the unit at a velocity sufficient to cause the bed to fluidize, providing enhanced turbulence and heat transfer; hence, increased waste destruction.

At-sea incineration involves the use of a ship-mounted liquid incinerator. The operations of incinerators at-sea versus on land are quite similar. The same equations apply for estimating emissions and the same control considerations would apply at-sea as on land. Historically, at-sea incinerators have not been equipped with acid gas scrubbers and have relied on the ocean's buffering capacity to neutralize acidic emissions.

Molten matrix systems employ molten salt or glass to achieve waste destruction. The matrix is maintained in a molten state in an electric furnace into which the waste is fed. Temperatures in the vicinity of 1100°C (2000°F) promote high destruction levels. The ash is trapped in the melt, thus providing relatively low particulate emission levels for these systems.

In high-temperature fluid wall units, waste is passed through a vertical heated porous carbon tube. Using electric heaters, the heat is applied to the external surface of the tube, generating temperatures in the tube in excess of 2200°C (4000°F). Nitrogen is forced from the outside to the inside of the porous tube, thereby preventing the waste particles from collecting on the wall. The required residence time is on the order of seconds, but the waste feed must be introduced in a consistent and finely divided condition.

Plasma arc destruction involves passage of waste through ultrahigh temperature electric arc plasma. Temperatures in excess of 2200°C (4000°F) promote high destruction efficiencies, and the gases produced by the unit can be passed through a conventional treatment unit such as a scrubber.

Destruction of wastes on super-critical water is based on the fact that many gases (including oxygen) and organic compounds are readily dissolved in water existing at super-critical conditions (greater than 374°C and 3200 psi). Waste is fed as an organic/water slurry containing 5 to 10 weight percent organics. The slurry is pressurized and heated to super-critical conditions using super-critical water. Oxygen or air is introduced with the feed and all organics are oxidized and the heat of combustion is released into the water.

The relative advantages and disadvantages of each type of technology are given in Table 1 of Appendix C. Because a vast majority of the thermal destruction performed to date has involved incineration (thermal oxidation), most of the emissions data available pertains to incinerators rather than the emerging technologies such as molten salt or plasma arc destruction. Therefore, unless otherwise noted, the discussion and data presented on thermal destruction in this document apply primarily to incineration technologies.

A typical thermal destruction system is composed of several subsystems. These include the waste feed system, primary and secondary (in some cases) combustion chambers, and exhaust gas conditioning systems. The flow diagram for a typical waste incineration system is shown in Figure 2.

The first step in a hazardous waste incineration system is the waste feed process. The configuration of the waste feed system is determined by the physical characteristics of the waste. Solid wastes, normally packed in fiber drums, are introduced to the combustion chamber by means of conveyer or pneumatic rams. Other solid wastes may require shredding or preheating before introduction to the incinerator. Liquids are injected into the incinerator by means of an atomization nozzle which uses steam or compressed air as an

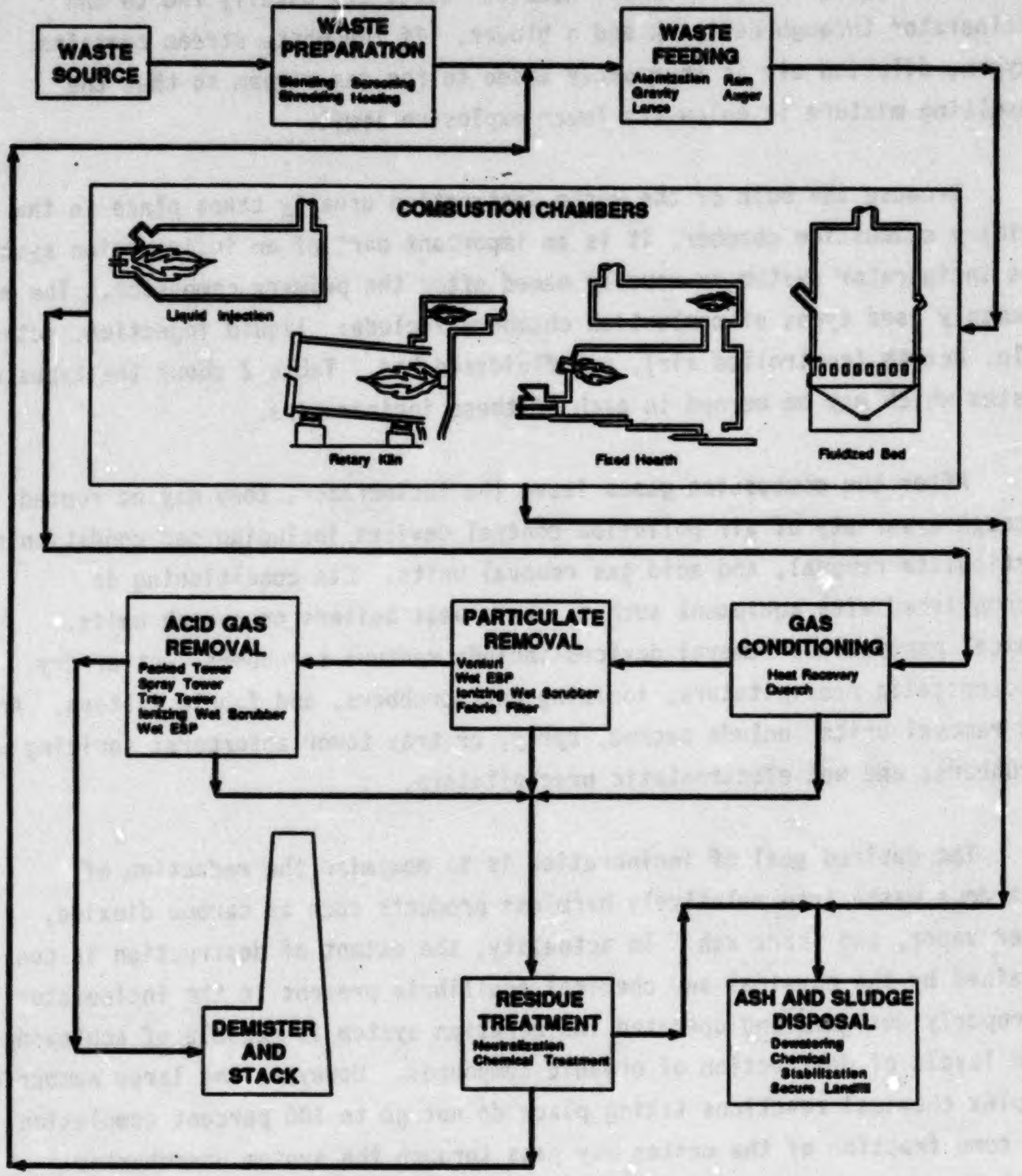

WASTE SOURCE
WASTE PREPARATION
Blending Screening
Shredding Heating
WASTE FEEDING
Atomization Ram
Gravity Auger
Lance
COMBUSTION CHAMBERS
Liquid Injection
Rotary Kiln
Fixed Hearth
Fluidized Bed
ACID GAS REMOVAL
Packed Tower
Spray Tower
Tray Tower
Ionizing Wet Scrubber
Wet ESP
PARTICULATE REMOVAL
Venturi
Wet ESP
Ionizing Wet Scrubber
Fabric Filter
GAS CONDITIONING
Heat Recovery
Quench
DEMISTER AND STACK
RESIDUE TREATMENT
Neutralization
Chemical Treatment
ASH AND SLUDGE DISPOSAL
Dewatering
Chemical
Stabilization
Secure Landfill

Figure 2. Process Flow Diagram for a Typical Hazardous Waste Incineration System

atomization fluid. Liquids with entrained solids may require screening to prevent clogging of the atomizer nozzle. Gases are usually fed to the incinerator through ductwork and a blower. If the waste stream contains oxygen, dilution air is frequently added to the gas stream so that the resulting mixture is below its lower explosive limit.

Because the bulk of the waste destruction usually takes place in the the primary combustion chamber, it is an important part of an incineration system. The incinerator system is usually named after the primary combustor. The most commonly used types of combustion chambers include: liquid injection, rotary kiln, hearth (controlled air), and fluidized bed. Table 2 shows the types of wastes which may be burned in each of these incinerators.

After the combustion gases leave the incinerator, they may be routed through a variety of air pollution control devices including gas conditioning, particulate removal, and acid gas removal units. Gas conditioning is accomplished with equipment such as waste heat boilers or quench units. Typical particulate removal devices include venturi scrubbers, wet or dry electrostatic precipitators, ionizing wet scrubbers, and fabric filters. Acid gas removal units include packed, spray, or tray tower absorbers; ionizing wet scrubbers; and wet electrostatic precipitators.

The desired goal of incineration is to maximize the reduction of hazardous waste into relatively harmless products such as carbon dioxide, water vapor, and inert ash. In actuality, the extent of destruction is constrained by the physical and chemical equilibria present in the incinerator. A properly designed and operated incineration system is capable of achieving high levels of destruction of organic compounds. However, the large number of complex chemical reactions taking place do not go to 100 percent completion, and some fraction of the wastes may pass through the system uncombusted. Further, some reactions may produce a number of simpler organic compounds (known as PICs or Products of Incomplete Combustion) which may also exit in the stack gases. PICs may include dioxin, formaldehyde, and benzo(a)pyrene

TABLE 2. APPLICABILITY OF AVAILABLE INCINERATION PROCESSES TO THE BURNING OF WASTE (BY WASTE TYPE)

Waste Type	Rotary Kiln	Liquid Injection	Fluidized Bed[a]	Fixed Hearth (Controlled Air)
Solids				
Granular, homogeneous	X		X	X
Irregular, bulky (pellets, etc.)	X			X[b]
High melting point (tars, etc.)	X	X[c]	X[c]	X
Organic compounds with fusible ash constituents	X			X
Unprepared, large, bulky material	X			
Gases				
Organic vapor-laden	X[d]	X[d]	X[d]	X[d]
Liquids				
High organic-strength aqueous waste often toxic	X[e]	X	X	
Organic liquids	X[e]	X	X	
Solids/Liquids				
Waste contains halogenated aromatic compounds	X	X[f]		
Aqueous organic sludge	X[g]		X	

Source: Reference 4

[a] Suitable for pyrolysis operation.

[b] Handles large material on a limited basis.

[c] If material can be melted and pumped.

[d] If properly fed into the incinerator.

[e] If equipped with auxiliary liquid injection nozzles.

[f] If atomizable liquid.

[g] Wastes which become sticky upon drying may cause feed problems.

and other polynuclear aromatic hydrocarbons. PIC formation is not restricted to the combustion chamber; the reactions which produce PICs may continue to occur in the combustion gases as they travel through the incineration system and out the exhaust stack.

Other pollutants which may be present in the incinerator exhaust gas include trace metals, particulate matter, carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and hydrogen chloride (HCl). In addition to emissions associated with the stack gas, incineration facilities can produce ash waste which may contain significant quantities of inorganic and some organic pollutants. Similarly, the use of air pollution control devices such as venturi scrubbers or fabric filters can produce solid and/or liquid wastes containing significant amounts of contaminants. Finally, each processing step and equipment component in the incineration process is capable of producing fugitive emissions. Fugitive emissions may occur from handling and transfer operations or from leaking connections and seals in pumps, valves, tanks, etc. When taken as a whole, they may actually represent the largest fraction of total pollutant emissions from a particular facility.

2.1.2 Key Parameters Affecting Emissions

Pollutant emissions from incineration facilities can be affected by a number of factors. Table 3 lists the major parameters which may influence emissions. While there is a large amount of data available which quantifies emissions measured in various incinerator studies, there is almost no information which actually provides numerical correlations for estimating emission rates by use of incinerator operating data. Therefore, while the following paragraphs discuss the relationships between operating conditions and emissions, and even the relative importance of the various operating parameters, this information does not provide an actual means of calculating emissions from operating data.

TABLE 3. FACTORS AFFECTING INCINERATION SYSTEM EMISSIONS

	Typical Importance to Emission Level		
Parameter	Particulates/ Metals	Volatile Organics	Acid Gases
Waste Characteristics			
Physical State	High	Medium	Low
Moisture Content	Low	High	Low
Particle Size	High	Low	Low
Thermal Content	Low	High	Low
Chemical Composition	High	High	High
Operating Characteristics			
Waste Feed Rate	High	High	High
Temperature	Medium	High	High
Residence Time	Medium	High	Medium
Excess Air Rate	Medium	Medium	Medium
Facility Size/Type	Medium	Medium	Medium
Atomization	Low	High	Low
Control Device Efficiency	High	Low	High

The following discussion of emissions and their controlling factors is divided into incinerator emissions (stack gas, bottom ash, and APCD residuals) and fugitive emissions (uncontrolled or undetected equipment leakage). For the purposes of this discussion, all incinerator types can be considered to be equivalent in emissions potential if properly operated. Exceptions are noted in the text.

Incinerator emissions are composed of fugitive emissions and the pollutants leaving in the combustion gas (organics, metals, particulate, acid gases, etc.), solids exiting the system (metals, etc.) with the combustion chamber bottom ash and APCD residuals, and liquids exiting the system (scrubber liquors, blowdown, etc.) The means by which pollutants are initially introduced to the incinerator include the waste streams (gas, liquid, or solid phase) as well as the auxiliary fuel (e.g., fuel oil, coal, or natural gas). Table 4 lists the typical range of uncontrolled stack emissions from incineration.

Undestroyed Organics--

In general, incinerators treating wastes from NPL sties must achieve a destruction and removal efficiency of either 99.99% for RCRA wastes or 99.9999% for PCB- or dioxin-contaminated wastes. In designing an incinerator to achieve such destruction and removal efficiencies, the factor which seems to most strongly affect the destruction and removal of any particular hazardous organic in an incinerator is the concentration of the compound in the waste feed stream. Assuming proper design and operation of an incinerator, the higher the compound's concentration in the waste stream, the greater the percentage of that compound destroyed in the incinerator (6). This percentage destruction is known as the destruction and removal efficiency (DRE). The heat of combustion, currently used to determine the relative incinerability of various compounds in a waste stream, apparently does not correlate well with the DRE. Furthermore, amongst the operational factors which might affect the DRE (e.g., combustion chamber temperature, residence time, and stack gas oxygen content), only combustion chamber temperature appears to be most strongly related to DRE (6). Table 5 presents the

TABLE 4. TYPICAL RANGES OF UNCONTROLLED EMISSIONS FOR INCINERATION

Contaminant	Stack Gas Concentrations	Emissions[a]	Fugitive Emissions (kg/hr)
Volatile Organics	0.1 - 1500 ug/m^3	0.065-980 mg/min	--[b]
Dioxins/Furans	Undectable[c]	-----	Undectable
Particulate Matter/Metals	0.5 - 23 g/m^3	320 - 15,000 g/min	Negligible
NO_x	10 - 4,000 ppm	17 - 6,900 g/min	Negligible
HF	20 - 200 ppm	20 - 200 g/min	Negligible
HCl	50 - 5,000 ppm	27 - 2,700 g/min	Negligible
SO_2	10 - 12,000 ppm	10 - 12,000 g/min	Negligible

[a] Based on an exhaust gas rate of 650 m^3/min.

[b] When compared to stack emissions, fugitive VO emissions typically occur at a rate equal to 4 to 80 percent of the stack VO emission rate.

[c] Emissiona re generally undetectable, though emissions of up to 12 ug/min have been measured.

TABLE 5. TYPICAL TEMPERATURES AND RESIDENCE TIMES FOR HAZARDOUS WASTE DESTRUCTION

Waste Type	Temperature (°C)	Temperature (°F)	Residence Time (seconds)	DRE (%)
Lean gases containing hydrocarbons of sulfur, fume streams	650-750	1200-1400	0.5 - 0.75	99
Liquid streams containing hydrocarbons, vapor streams containing CO or ammonia	900-1000	1600-1800	1.0 - 2.0	99.99
Halogenated hydrocarbons liquids and vapors, long chain hydrocarbons, waste liquids	1000-1100	1800-2000	1.5 - 2.0	99.99
Combustible solids	1100-1300	2000-2400	1.5 - 2.0	99.99
NO_x or compounds with bound nitrogen (reducing atmosphere, i.e., excess fuel)	1300-1400	2400-2600	1.0 - 2.0	99.99
PCBs, dioxins	1200-1300	2200-2400	1.0 - 2.0	99.9999

temperatures and residence times at which various wastes may be destroyed to a given DRE.

Products of Incomplete Combustion--

PICs are compounds found in the stack gases, but not detected in the waste feed stream. Several possible explanations for these compounds exist (6): 1) The PICs are present in the feed stream in concentrations below detection limits, and experience little or no destruction. As the volume of surrounding waste is decreased, the presence of the PICs becomes easier to detect. The trend of decreasing DRE with decreasing waste feed concentration supports this and could explain the presence of many of the PICs detected. 2) Some PICs are introduced from non-waste feed sources. Chloroform, for example, has been shown to be introduced to the system from the scrubber makeup water. Fuel oil can also be a source for PICs. 3) Compounds which are actually created in the combustion process. The presence of simple stable compounds such as chlorinated methanes, ethanes, and benzene compounds in most stacks supports this hypothesis.

Dioxins and furans are incinerator combustion by-products which have been subjects of intense scrutiny by the scientific, regulatory, and public sectors. Most dioxins and furans emission studies have been conducted on municipal waste incinerators, and only limited data are available for hazardous waste incinerators. EPA studies on 17 hazardous waste incinerators, kilns, and industrial boilers discovered only five which were emitting detectable levels of dioxins and furans. Table 6 presents these data. As a means of comparison, average dioxins and furans emissions compiled from an EPA study of 22 municipal waste incinerators were nearly 1,000 times greater than those from the hazardous waste incineration facilities (7).

This large difference in dioxin and furan emissions is due to differences in operating practices between hazardous waste and municipal incinerators. Hazardous waste incinerators are typically well mixed, burn at elevated temperatures, and have an excess oxygen content of at least 3%. Municipal incinerators are relatively large, have pockets of poor mixing, and may have cold spots where dioxins and furans can form.

TABLE 6. STACK CONCENTRATIONS DIOXINS AND FURANS FROM HAZARDOUS WASTE INCINERATION FACILITIES

Facility Type	Dioxins (ug/m^3)	Furans (ug/m^3)
Commercial Rotary Kiln/ Liquid Injection Combustion Incinerator	ND[a]	ND-1.7
Fixed Hearth Incinerator	16	56
Liquid Injection Incinerator	ND	ND
Horizontal Liquid Injection Incinerator	ND	7.3
Incinerator Ship	ND	0.3-3
4 Lime/Cement Kilns	ND	ND
Fixed Hearth Incinerator	ND	ND
Rotary Kiln/Liquid Injection	ND-48	0.6-95
Industrial Boiler	75-76	ND
Industrial Boiler	0.64-0.8	ND
Industrial Boiler	ND	ND
Industrial Boiler	ND	ND
Industrial Boiler	1.1	ND

ND - not detected.

Source: Reference 7

Metals--

The metals introduced to the incinerator via the waste feed stream are not destroyed. Depending on their boiling point and the combustion temperatures, they can either be volatilized or remain a solid. Volatilized metals will exit the stack as a gas or they will condense onto particles in the stack gas stream. Non-volatilized metal particles can be fluidized and swept up into the combustion gas or leave the incinerator in the bottom ash. The partitioning of a metal between the stack gas and the bottom ash is primarily dependent upon the volatility of the metal. Metals with higher volatility (e.g., mercury, selenium, antimony, cadmium, and lead) generally have a higher proportion of the starting material exiting in the stack gas, and lower volatility metals (e.g., nickel and chromium) tend to show enrichment in the bottom ash (8). Because the combustion process provides no inherent control over stack emissions of metals, air pollution control devices such as venturi scrubbers or ionizing wet scrubbers are used to reduce the atmospheric discharge of metals.

Particulate Matter--

The waste feed, auxiliary fuel, and combustion air can all serve as sources for particulate emissions from an incineration system. Particulate emissions may result from inorganic salts and metals which either pass through the system as solids or vaporize in the combustion chamber and recondense as solid particles in the stack gas. High molecular weight hydrocarbons may also contribute to particulate emissions through several possible mechanisms. First, the molecule can self-nucleate and grow into a particle by adsorption of other organic molecules (however, high temperatures tend to combust all organic compounds to gases). Also, inorganic compounds such as halogens can possibly dehydrate large organic molecules leading to nucleation and particle growth. Finally, inorganic oxides may also adsorb high molecular weight organics yielding a particle saturated with the adsorbed organic.

The molecular weight and geometry of particles is determined by the incinerator operating conditions (temperature, residence time, and oxidizing or reducing environment). Emissions of these particles are strongly affected by the waste and fuel compositions, incinerator type and operation, and the effectiveness of the air pollution control devices. Particulate loading in uncontrolled combustion chamber exhaust gas varies with waste loading, but generally ranges between 0.5 and 23 g/m^3 (0.2 and 10 grains/dscf). Controlled stack gas concentrations usually fall in the 34 to 110 mg/m^3 (0.015 to 0.05 grains/dscf) range (9). Incinerators treating wastes from NPL sites will generally be required to meet RCRA requirements governing particulate emissions, i.e., requiring an emissions limit of 0.08 grains/dscf corrected to 7% of O_2.

NO_x--

Achieving high levels of destruction of organic wastes is directly related to combustion chamber temperature: the higher the temperature, the greater the DRE of organics. Unfortunately, the fixation of nitrogen and oxygen to form NO_x also increases with combustion temperature. Excess air and high heat release are also contributors to NO_x formation. NO_x is generally not a problem unless there are bound nitrogen atoms in the waste, e.g. amines. In such cases, two stage combustion or emissions controls may be needed.

Carbon Monoxide--

Carbon monoxide emissions are generally low (<25 ppm) in commercial incinerators due to the high operating temperatures and excess oxygen maintained in the process. Elevated CO concentrations of (up to 800 ppm) have been measured in several different types of incinerators (7). However, even where carbon was not being fully oxidized, the destruction and removal efficiencies were >99.99%.

Acid Gases--

Hazardous waste incineration may also produce acid gases. These include oxides of sulfur (SO_x), and halogen acids (HCl, HF, and HBr). The sulfur, chlorine, fluorine, and bromine contents of the waste and fuel feed determine the emission levels of their respective acid gases. The concentrations of these elements range widely amongst different wastes; consequently, the resulting acid gas emissions will also show wide variability. Incinerators treating wastes from NPL sites will generally be required to meet RCRA requirements governing HCl emissions.

Bottom Ash and APCD Residues--

Incineration of wastes containing substantial quantities of ash or halogens will produce solids which will be found in the combustion chamber bottom ash and in the residues collected by the APCDs. In the bottom ash and APCD residues, the content of pollutants such as hazardous organics or metals is dependent primarily upon the pollutant's waste feed concentration and volatility. To determine the proper method of disposal, the residues must be analyzed to characterize their hazardous properties.

Fugitive Emissions--

Fugitive emissions in an incineration facility are defined as uncontrolled gas emissions coming from any operation or equipment other than the exhaust stack. Sources for fugitive emissions include leaking valve and pump fittings, flanges, storage tanks, and sampling and instrument connections. Correlations have been developed which relate the fugitive emission rate to number and size of each of these sources (10,11). Previous studies of both predicted and measured emissions from incineration facilities have indicated that atmospheric pollutant concentrations at close proximity to a facility can be more strongly affected by fugitive losses than by stack emissions (12,13). This is due in part to the low temperatures and proximity to ground level of typical sources of fugitive emissions.

2.1.3 Possible Control Technologies

Three types of control strategies may be used for reducing the air emissions from incineration. These are downstream treatment of the gases produced during incineration, modification of operating parameters to reduce the production of pollutant gases, and control of fugitive emission sources. Each strategy is described, in turn, below.

Incinerator air pollution control devices (APCDs) include venturi scrubbers, packed bed scrubbers, electrostatic precipitators, ionizing wet scrubbers, and fabric filters. Table 7 shows the applicable pollutants, pressure drops, and descriptions for each of these APCDs (14). Methods for controlling specific types of emissions by treatment of the flue gas exhausted from the combustion chamber are discussed in the following paragraphs.

Organic Compounds--

Two recent EPA incinerator studies in which combustion chamber ash and scrubber water were analyzed found only very small quantities of organic pollutants in these effluent streams (15,16). While these findings indicate that the DRE for organic compounds is due primarily destruction rather than capture and removal, the actual mechanism of capture is not well understood.

This is true also for dioxins and furans. Two likely modes of capture include condensation and capture as a particle, as well as attack and capture by caustic reagents. These modes of capture are enhanced by lowering flue gas temperatures, scrubbing the flue gas with caustic reagents, and capturing the particulate matter in a high efficiency particle collector. Spray drying, followed by fabric filtration, has been found to be effective and superior to the spray drying/ESP system (17). Table 8 presents data on dioxins and furans control device efficiencies.

Particulate Matter/Metals--

Wet electrostatic precipitators, venturi scrubbers, and ionizing wet scrubbers are frequently used in industry for particulate control. Wet ESPs have high particulate control efficiencies. At high ratios of collector plate surface area to gas volumetric flow rate (i.e. in the range of 170 minutes/meter), wet ESPs can control particulate emissions to less than 0.45 mg/m^3 (0.02 gr/dscf). Venturi scrubbers are less effective and require very high pressure drops to remove fine particles. They are capable of removing 80 to 95 percent of entrained particulate matter (17). Generally, scrubbers control hazardous metals less efficiently than they do general particulate

TABLE 7. INCINERATION SYSTEM AIR POLLUTION CONTROL DEVICES

Device	Pollutant	Pressure Drop (m of H_2O)	Description
Afterburner	Gaseous hydrocarbons		Completes combustion of gases not destroyed in primary incineration. Auxiliary fuel required.
Venturi scrubber	Particulate, HCl, SO_2, NO_x, HCN	0.25 - 1.25	High efficiency. High energy requirement. Requires downstream mist eliminator.
Electrostatic precipitator	Particulate	<0.01	Low operating cost. High efficiency for fine particles. Dust resistivity problem.
Ionizing wet scrubber	Particulate, gases		Low energy consumption. No dust resistivity problem.
Fabric filter	Particulate	0.05 - 0.2	High efficiency for fine particles. Not for corrosive or hot gases (>250°C).

Source: Reference 14

TABLE 8. SPRAY DRYER CONTROL OF DIOXINS AND FURANS

	Percent Removal		
Compound	Spray Dryer + ESP	Spray Dryer + Fabric Filter (High Temperature)	Spray Dryer + Fabric Filter (Low Temperature)
Dioxins			
tetra CDD[a]	48	<52	>97
penta CDD	51	75	>99.6
hexa CDD	73	93	>99.5
hepta CDD	83	82	>99.6
octa CDD	89	NA	>99.8
Furans			
tetra CDF[b]	65	98	>99.4
penta CDF	64	88	>99.6
hexa CDF	82	86	>99.7
hepta CDF	83	92	>99.8
octa CDF	85	NA	>99.8

[a] CDD - chlorinated dibenzo-para-dioxins.

[b] CDF - chlorinated dibenzofurans.

matter. For metals, the control efficiency is inversely dependent on the metal's volatility, i.e., with decreasing control efficiency as the volatility increases (8).

NO_x--

Control of NO_x in the flue gas is relatively difficult and expensive because unreactive NO usually comprises up to 95 percent of the total NO_x. However, selective catalytic reduction (SCR) offers an effective means for NO_x reduction. Prior to SCR treatment, the stack gas must undergo acid gas and heavy metals control. This method is capable of removing 80 to 90 percent of the total NO_x (17). The effectiveness of SCR can be enhanced further through the use of special lower temperature catalysts which are resistant to HCl (18).

Acid Gases--

Acid gases such as HF, HCl, and SO_2 may be controlled effectively with wet, dry, and semi-dry scrubbers. Reactive acid gases including HF and HCl are relatively easily controlled (water can be used as a sorbent). However, efficient control of SO_2 requires an alkali sorbent. Table 9 discusses the effectiveness of acid gas controls in various configurations.

Dry scrubbers are the least effective means of acid gas control because the absorbent requires extended residence time in the gas. A more effective means of control is spray drying or semi-dry injection. Wet scrubbing and combined semi-dry/wet systems have the highest control effectiveness; however, the advantages of these systems has to be balanced against possible higher costs due to waste water treatment and increasing system complexity (17).

The following three paragraphs describe operational (in furnace) methods of emission control for incineration.

TABLE 9. EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL)

	Pollutant		
Control System	HCl	HF	SO_2
Dry Injection + Fabric Filter (FF)[a]	80	98	50
Dry Injection + Fluid-Bed Reactor + ESP[b]	90	99	60
Spray Dryer + ESP	95+	99	50-70
(Recycle)[c]	(95+)	(99)	(70-90)
Spray Dryer + Fabric Filter	95+	99	70-90
(Recycle)[c]	(95+)	(99)	(80-95)
Spray Dryer + Dry Injection + ESP or FF[d]	95+	99	90+
Wet Scrubber[e]	99	99	90+
Spray Dryer + Wet Scrubber(s) + ESP or FF[e]	99	99	90+

Source: Reference 17

[a] T = 160-180°C (320-356°F).

[b] T = 230°C (446°F).

[c] T = 140-160°C (284-320°F).

[d] T = 200°C (392°F).

[e] T = 40-50°C (104-122°F).

T = the temperature at the exit of the control device.

Organic Compounds--

Operational variables which have the most significant potential for reducing organic emissions include combustion chamber temperature, residence time, and oxygen content in the combustion atmosphere. Table 2-5 shows typical temperatures and residence times at which various wastes might be most completely destroyed.

Particulates/Metals--

Incinerators have no inherent ability to destroy non-combustible materials, therefore facilities burning wastes with a potential for high ash or particulate emissions will generally route stack gases through air pollution control devices such as scrubbers, wet electrostatic precipitators, or fabric filters to prevent excessive emissions. Frequently, quench units are used upstream from a venturi scrubber in order to cool the gases and promote particle growth. When precipitators are used, a scrubber is often placed downstream to absorb gaseous components.

NO_x--

Most of the potential in-furnace process modifications (peak flame temperature reduction, low excess air, and low rate of heat release) by which NO_x production could be reduced run contrary to achieving high DRE levels for organic pollutants. However, staged combustion is one approach which can reduce NO_x emissions while still getting high DREs. Staged combustion, also known as reburning, involves initial burning of waste under fuel rich (reducing) conditions in the primary combustion zone followed by addition of air to complete combustion in a secondary combustion zone. Another method of NO_x control involves ammonia injection in the upper combustion area. Because the reaction of ammonia and NO_x is quite temperature sensitive, this method, known as Thermal DeNO_x, requires careful selection of the ammonia injection point (17).

Fugitive emissions may also be a concern at incineration facilities. The primary means of controlling or reducing fugitive emissions are through equipment selection and the establishment of effective inspection and maintenance programs.

2.2 AIR STRIPPING OF GROUND WATER

2.2.1 Emission Sources

Air stripping of ground water effectively transfers volatile organic contaminants from the liquid-phase to the gas-phase. A typical ground-water treatment facility may contain some or all of the following components:

1) Recovery wells;
2) Oil/water separator;
3) Storage/surge tank;
4) pH Adjustment;
5) Inorganic treatment;
6) Air stripping tower;
7) Off-gas treatment;
8) Semi-volatile organic compound treatment;
9) Filters; and
10) Injection wells.

Air stripping towers (see Figure 3) use packing media to optimize the mass transfer of VOs in the ground water to the air. The upstream pH adjustment serves to enhance removal efficiencies and to keep the packing material in the tower clean. The water is introduced at the top of the tower through spray nozzles and allowed to slowly flow down through the media. The packing media acts to retard the water flow and increase the effective surface area. A blower or blowers, forces air up from the bottom of the tower, countercurrent to the direction of water flow. The saturated air containing the volatiles is emitted at the top. The stripper exhaust may require treatment, depending on the concentration and the nature of the VOs present in the ground water.

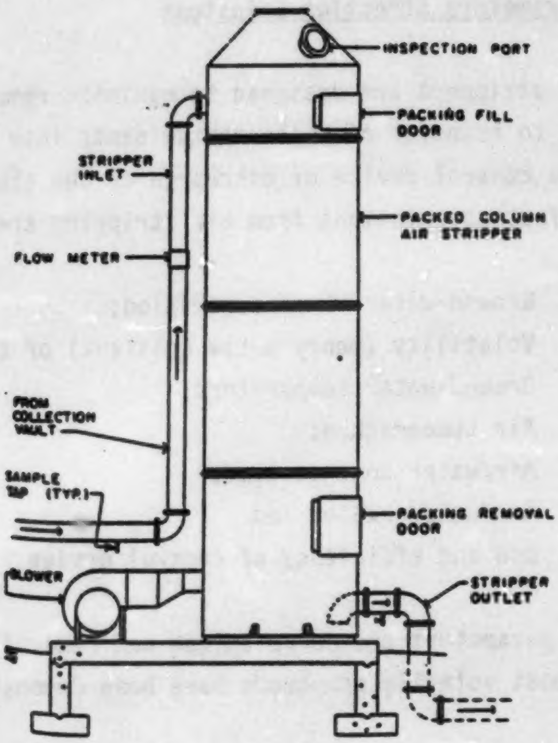

INSPECTION PORT
PACKING FILL DOOR
STRIPPER INLET
PACKED COLUMN AIR STRIPPER
FLOW METER
FROM COLLECTION VAULT
SAMPLE TAP (TYP.)
PACKING REMOVAL DOOR
BLOWER
STRIPPER OUTLET

Figure 3. Typical Air Stripper and Blower

The primary source of emissions from air stripping is the stripper exhaust. However, other sources may exist. Any place upstream of the air stripping tower where the water is in direct contact with the atmosphere, such as separators, holding tanks, treatment tanks, or conduits, is an emission source. Fugitive losses from pumps, valves, and flanges are usually not significant due to the dilute nature of the ground-water contamination.

2.2.2 Key Parameters Affecting Emissions

Air strippers are designed to maximize removal of VOs from ground water leading to transfer of these contaminants into air and eventual treatment in a control device or discharge to the atmosphere. The key parameters affecting emissions from air stripping are:

- Ground-water VO concentration;
- Volatility (Henry's Law Constant) of the VOs;
- Ground-water temperature;
- Air temperature;
- Air/water contact time;
- Air/water ratio; and
- Use and efficiency of control device.

Many of these parameters can be optimized and removal efficiencies in excess of 99.5% for most volatile compounds have been demonstrated (20,21).

The design of a packed tower requires the evaluation of various design parameters on the size of the packed towers. Kavanaugh and Russel (22) have published a useful introduction to the topic which is summarized below. Given the influent organic loading, the desired effluent water quality, system flow rate, and design temperature, the design is as follows:

1. Select an efficient packing material and determine its headloss and mass transfer characteristics from commercially available data.

2. Select a stripping factor (e.g., 1.2-1.4).

3. Select a gas phase pressure drop (e.g., 100 N/m^2 per m).

4. Determine the number of transfer units.

5. Using the headloss correlation, determine the allowable superficial gas rate.

6. Based on items 2 and 5, determine the liquid loading rate and the diameter of the column.

7. Evaluate the practicality of the liquid loading rate and, if necessary, reduce the air headloss.

8. Optimize the cost of the system by evaluating various stripping factors and air headlosses.

Reference 22 should be consulted for an explanation of the above terms. Obviously, the design of a packed tower is a complex process and multiple, interrelated variables must be considered.

Volatility increases with temperature, so heating the ground water and/or the air stream enhances removal. The air blower heats the air during compression; heat exchangers can be used to preheat the ground water.

The rate of volatilization is affected by the air-to-water contact time and the air-to-water ratio. The contact time can be increased by increasing the height of the tower, by slowing the rate of water percolation through selection of packing material, or by increasing the effective surface area of the tower through selection of packing material or decreasing the average droplet size. The spray pattern can be deleteriously altered by plugging of individual spray nozzles or if the distance between the nozzles and packing is incorrect, and this may result in short circuiting of ground water through the air stripper, thereby reducing removal efficiency. Air-to-water ratios are typically 200:1 for effective removal.

For upstream emission sources, VO emission rates are dependent on similar parameters to those affecting air stripper emissions such as VO concentration in the ground water, ground water temperature, and volatility of the VOs. Other key parameters for upstream emission sources are the surface area of the exposed ground water, the degree of agitation of the water surface, and the residence time of the water at any exposed location. Since air stripping is typically a very efficient treatment process, any emissions that occur upstream of the air stripper represent emissions that would otherwise occur at the air stripper. Therefore, if emissions from the air stripper are uncontrolled, then upstream emissions may generally be ignored. However, if air stripper emissions are controlled, then consideration of upstream emissions is warranted as these emission would otherwise be largely controlled. Emissions from open tanks may be a significant emission source and emissions can be measured or predicted as discussed in Section 5.

2.2.3 Control Technologies

The effect of air stripping of ground water is often to translate a future health risk from drinking contaminated ground water, into an immediate, albeit frequently lower, health risk from breathing contaminated air. However, the air stripper exhaust can easily be routed through an emissions control device. Two control technologies are typically used: carbon adsorption and incineration. If an incinerator is in concurrent service, the exhaust from the air stripping tower can be used as makeup air to the combustion chamber. Otherwise, vapor-phase carbon adsorption with or without steam regeneration is usually the most cost-effective treatment.

Carbon adsorption systems (CAS's) typically contain multiple beds of granulated activated carbon. The exhaust gas from the air stripping must be first treated by a preheater to reduce the relative humidity of the gas stream to below 50 percent. Very high humidities drastically reduce the adsorptive capabilities of the activated carbon. A fan forces the vapor through the carbon beds. Some type of diffuser or diaphragm baffle can be used to increase the flow path and the contact time. The flow may be in parallel or in series with a second bed functioning as a polishing unit. The carbon beds require either periodic replacement or cleansing with low pressure steam. The solvent-laden steam from regeneration is passed through a condenser and the condensate may be sent to a solvent recovery facility. The regeneration cycle can be automatically activated based on the theoretical breakthrough of the least adsorbed component, or operating cycles can be set in response to a preset concentration monitored in the stack. Flammable or explosive conditions may exist in the CAS and appropriate safety precautions are required.

Typically, the adsorption capacity increases with the molecular weight of the VO being adsorbed. Unsaturated compounds are usually more completely adsorbed than saturated compounds, and cyclical compounds more than straight-chain compounds. The adsorption capacity is increased by operating at relatively low temperatures (50-55°C) and high VO concentrations. Carbon adsorption can be used on gas streams with about 200 to 10,000 ppm of VOs. The removal efficiency varies with concentration with removals of 95 to 99% possible for inlet concentrations exceeding 1,000 ppm. CAS's do not work well for two types of organic compounds: highly volatile compounds (molecular weight < 45) do not adsorb readily on carbon, high molecular weight compounds (molecular weight > 130) that have low volatility are strongly adsorbed on carbon and are difficult to remove. Design information has been published by the EPA (23). Control efficiencies, and thus emissions, will also be dependent upon the manner of operation of the control system. For example, a system that initiates regeneration when breakthrough is detected may have higher emissions than a system that automatically regenerates more frequently.

Emissions from sources upstream of the air stripping tower can best be controlled by covering or enclosing the source, to make the system as closed as possible.

2.3 IN-SITU VENTING

In-situ venting is a technique which uses soil aeration to treat subsurface zones of contaminated soil for VOs. There are several techniques available which either 1) remove the VOs from the soil or 2) cause migration of the VOs away from a point of concern (the basement of a single structure, for instance, which is endangered by collection of explosive or toxic vapors). Most of the discussion describing in-situ venting and key parameters affecting emissions in this report is taken from Crow, et al. (24).

2.3.1 Emission Sources

Two basic types of aeration exist: active aeration, which uses either vacuum or positive pressure pumping, and passive aeration, which depends upon natural driving forces for soil gas displacement. Active aeration through vacuum pumping is the only available means of actually extracting the volatile constituents from the soil. Positive pressure and passive aeration serve only to displace the VOs, causing migration away from endangered structures. The latter two system types may not be suitable for use at most NPL sites, except perhaps where the site is located adjacent to basements, sewers, or other subsurface structures.

An example of a vacuum ventilation system is shown in Figure 4; it consists of a vapor recovery well (i.e., a perforated pipe placed vertically or horizontally into the subsurface soil for purposes of ventilation), a vacuum source, and an emissions control device. A vacuum is applied to the vapor recovery well by the vacuum source. The flow of gases results in a rich mixture of VOs being pulled into the recovery well. The VO-rich gases pass through the vacuum source and are treated in the emissions control device to remove potential air pollutants.

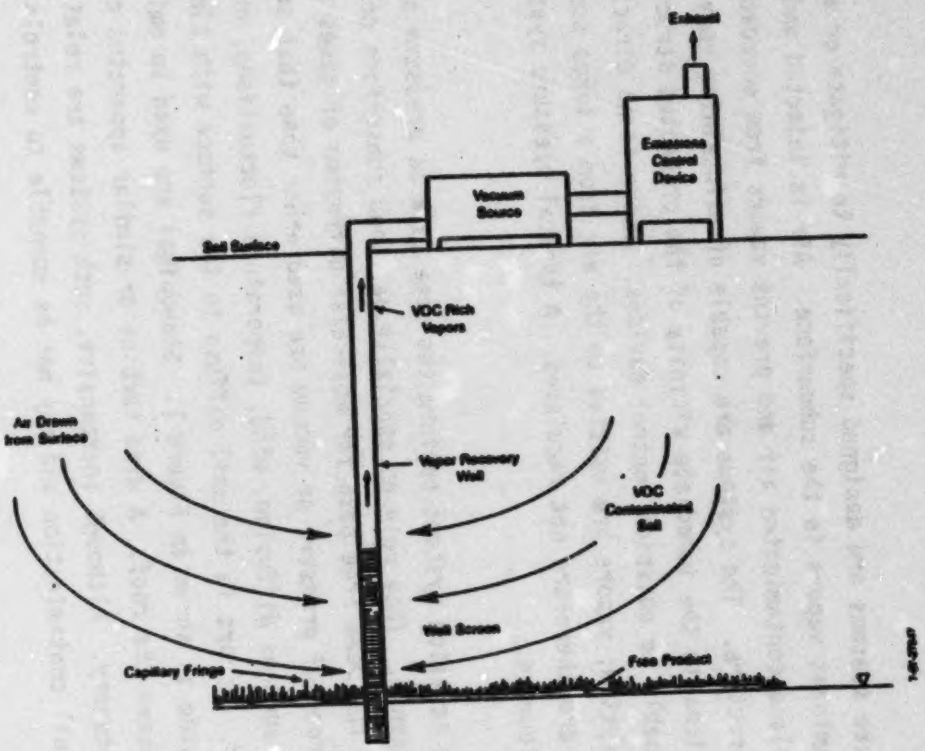

Exhaust
Emissions Control Device
Vacuum Source
Soil Surface
VOC Rich Vapors
Air Drawn from Surface
Vapor Recovery Well
VOC Contaminated Soil
Well Screen
Capillary Fringe
Free Product

Figure 4. An Example of a Subsurface Ventilation System (Vacuum Type)

Source: Reference 24.

As a vacuum is applied to a vapor recovery well, gas flows from the soil into the well and to the vacuum source. At the same time, air must enter the soil to replace the soil gas removed by the ventilation system. Air flow can be altered by an impermeable barrier at the surface and by an air intake well. Air-flow patterns during vacuum aeration are illustrated in Figure 5. These devices can be used to direct air flow and optimize performance of subsurface ventilation systems.

Pressure systems are designed specifically to mitigate or avoid the effects of contaminant vapors in the subsurface. Air is injected under pressure to displace contaminated air and prevent vapors from encroaching upon the protected structure. The systems are capable of maintaining very low vapor concentrations in the immediate vicinity of the protected structure. They are not amenable to emission control devices. There is no direct exhaust from a pressure system; vapors are emitted to the air from a large surface area of soil and are therefore not regulated. A typical pressure system is illustrated in Figure 6.

Passive aeration systems perform the same task as pressure systems, but at minimal expense. They rely on specially designed subsurface collection systems to reduce the mean free path for molecular diffusion of gases through the soil. No sources of pressure or vacuum are used other than that supplied by natural forces such as diffusion, wind, temperature fluctuations, or infiltrating water. Vapors in the soil diffuse to the surface with time. A simple passive system is shown in Figure 7. Standpipes are used to emit the extracted vapors above the roof. A wind turbine or similar apparatus can be used to enhance recovery. Although inexpensive, such systems are relatively slow in removing soil contamination and may not be amenable to controls.

Case studies reported by Crow, et al. (24) showed recovery rates ranging from 1 to 110 kg of organic contaminants per day. However, recoveries up to 900 kg/day of volatiles from ventilation of a single recovery well, have been reported from an NPL site (25); this can be considered to be a maximum rate.

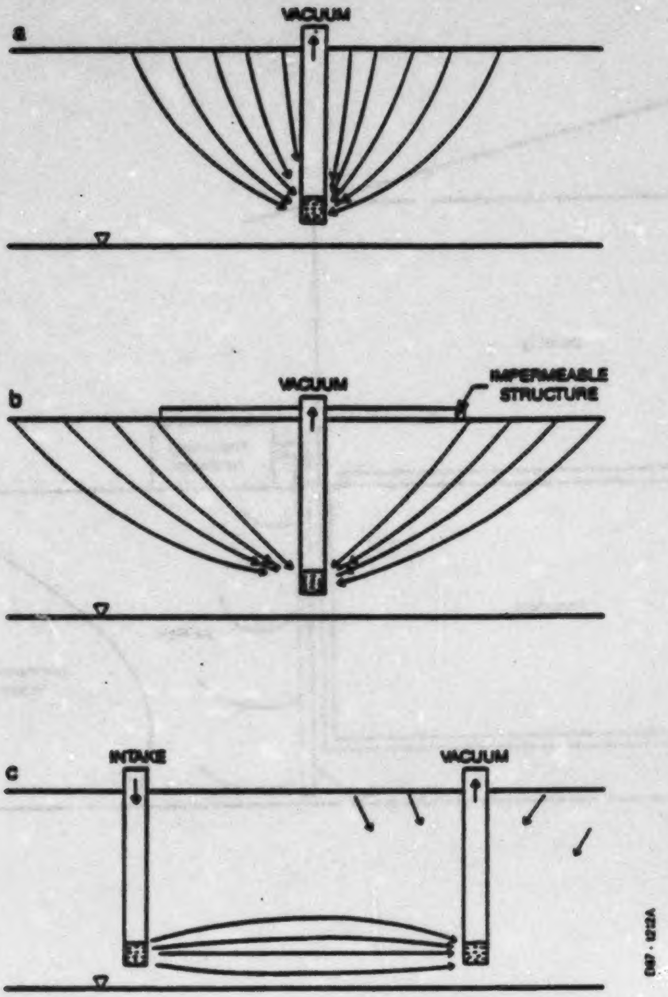

a
VACUUM
b
VACUUM
IMPERMEABLE
STRUCTURE
c
INTAKE
VACUUM
D87 · 1212A

Figure 5. Illustration of air-flow patterns active in subsurface ventilation systems employing (a) vacuum, (b) impermeable barriers, and (c) air intake wells.

Source: Reference 24.

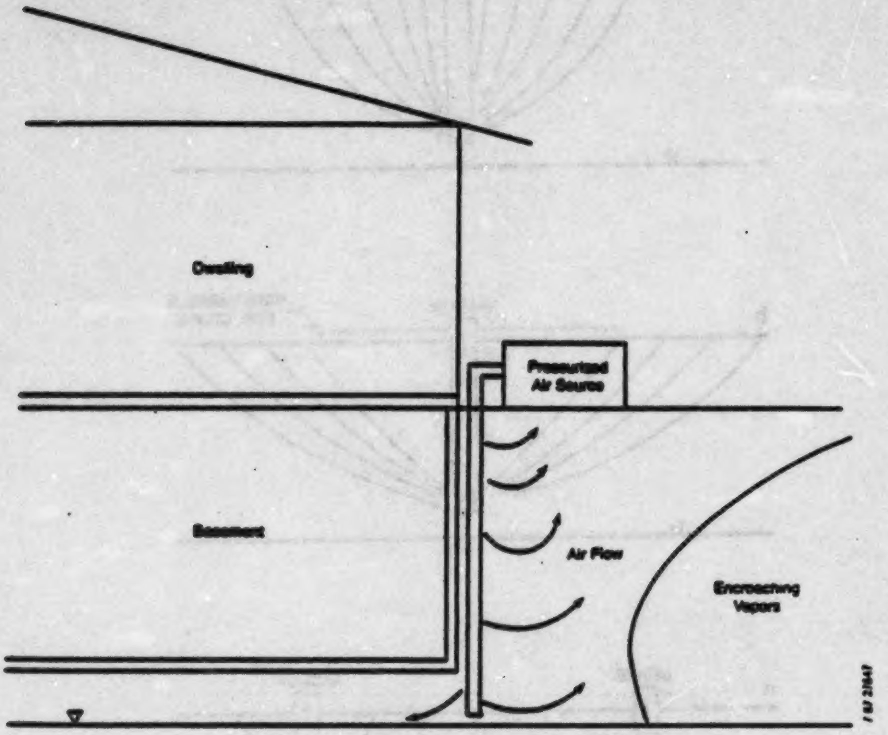

Dwelling
Pressurized Air Source
Basement
Air Flow
Encroaching Vapors

Figure 6. Pressure subsurface ventilation system designed to prevent encroaching vapors from entering through the basement of a dwelling.

Source: Reference 24.

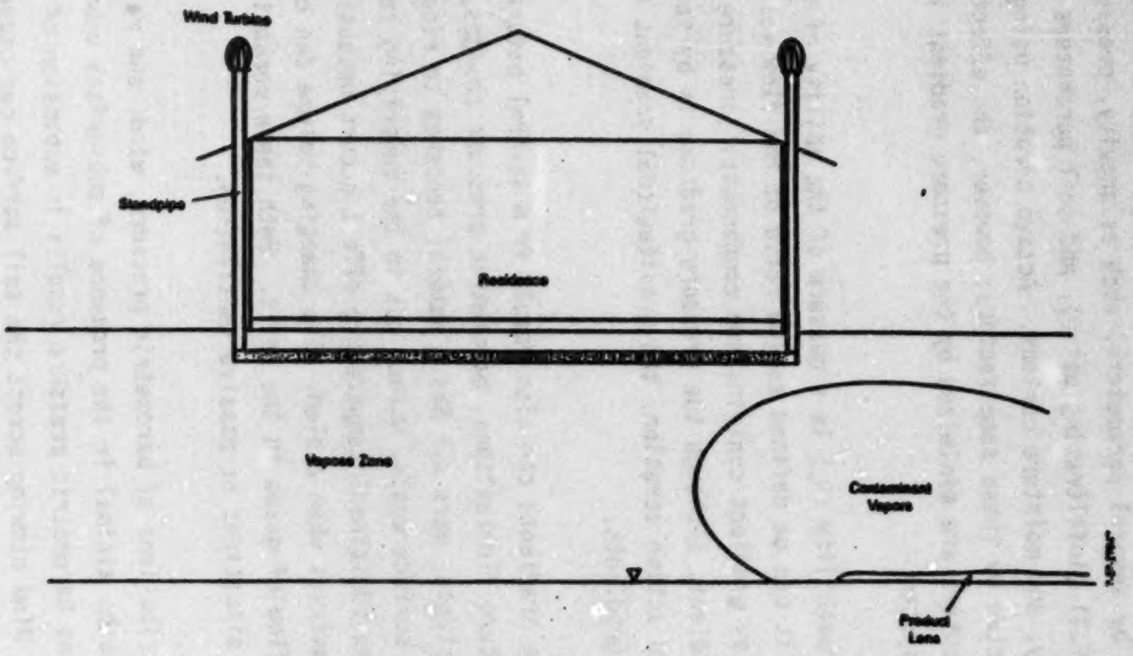

Wind Turbine
Standpipe
Residence
Vapose Zone
Contaminant
Vapors
Product
Lens

Figure 7. Passive Subsurface Ventilation System Utilizing Horizontal Perforated Pipe.
Source: Reference 24.

2.3.2 Key Parameters Affecting Emissions

The flow of gas through a subsurface environment is governed by the physics which pertain to the flux of gas through any porous medium. Natural flow is affected by several parameters, such as gravity, pressure, temperature, wind, rainfall (infiltrating water), and soil parameters such as porosity, density, and moisture content. Active aeration using vacuum or pressure is affected by these same factors; however, the effects of many of the natural parameters are minimized by the pressure gradient induced by the active aeration system.

Air permeability (k_a) is a measure of the ability of soils to transmit gases. It can be defined as the ratio of the flow volume to the flow gradient. The flow gradient contains two components: pressure gradient and gravitational gradient, although the pressure gradient is by far the primary driving force. In active aeration, the gravitational gradient is overcome by induced pressure gradients.

Pressure gradients can also result from several natural sources, including temperature fluctuations, barometric pressure changes, wind, and rainfall. For instance, warm air has a natural tendency to rise above cooler air. As the soil surface cools, warmer gas in the underlying soil will rise to the surface. An additional temperature effect occurs because gases expand when heated and contract when cooled. The changing volume can create a constant ebb and flow of gases in the soils. Both these mechanisms would only be significant in situations of passive ventilation.

The contributions of barometric pressure, wind, and rainfall on gas movement would also be minimal in the presence of subsurface ventilation systems. Decreasing barometric pressure results in expansion of soil gases, causing aeration. Wind blowing across the soil surface can cause mixing of the upper few centimeters of soil gas by creating a small pressure gradient. Infiltration of water through rainfall causes water to enter the soil pore space and gas to be expelled.

The most important external factors which affect soil gas movement are the properties of the soil itself: porosity, density, and moisture content. At a given soil density, the volume of soil solids is constant. The balance of the soil volume is termed the pore space (porosity) and may be filled with liquid or gas as shown in Figure 8. At a given soil density, the pore space is also constant. Since the mass flow of gas is restricted to the gas volume, there is a complex interaction of density, water content, and porous space available for gas flow.

In a dry soil, the porosity is equal to the gas volume and proportional to the air permeability. However, it is the effective porosity, or that calculated for connected pore space, that controls flow, since the majority of gas flow is through large, continuous pores in the soil. Dense soils, or those which have been remolded and compacted, are less permeable to air than natural soils. Clay soils are less permeable than sandy soils, for although many clay soils have porosities greater than sandy soils, the effective porosities are smaller.

Moisture content is one of the most important parameters influencing the air permeability of soils. Moisture in the soil resides in the pore space with the gas, decreasing the space available for gas flow and therefore the air permeability of soils. Air permeability decreases rapidly at relative water saturation values greater than 50% (i.e., <50% air space). Large, continuous pores are most effective at transmitting gas and are not filled with water until the soil approaches saturation.

The water- to gas-filled pore space relationship can be related to the water-holding capacity of the soil. Fine-textured soils have finer pores and tend to hold more water against the force of gravity. The finer, less continuous pores and greater water content make fine-textured soils much less permeable to air than their coarse-textured counterparts. The coarser-textured soils are more applicable to subsurface ventilation.

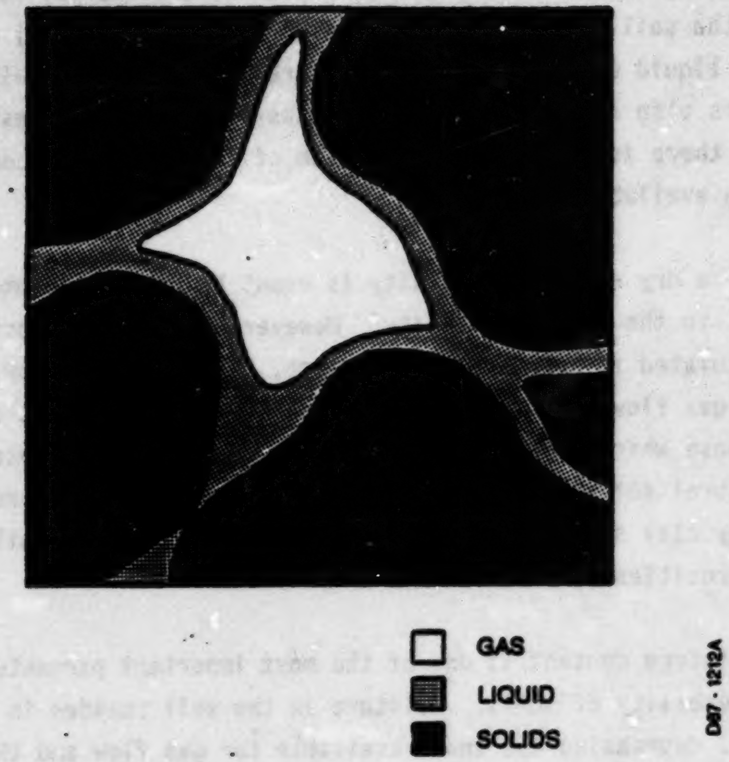

GAS
LIQUID
SOLIDS
D87 - 1212A

Figure 8. **Cross-sectional view of the soil system. (The soil is a three-phase system consisting of solids, liquids, and gases. Only the gas space is available for movement of VOC vapors.)**

2.3.3 Possible Control Technologies

To prevent turning a subsurface pollution problem into an air quality problem, some states regulate the emission of vent gas to the atmosphere. Several options are available for emissions control of exhaust from subsurface ventilation systems. The most effective techniques available for control include condensation, carbon adsorption, and incineration.

Condensation is a means of recovering organic compounds from the exhaust streams. The vent gas is cooled to decrease the vapor pressure of the volatile organic compound and trigger condensation. Water also condenses at these temperatures, and some form of separation process is necessary. In addition, the temperature should be low enough to minimize vapors present in the condenser which could potentially be released from the system. Even at low temperatures, this method is not completely efficient at removing contaminant vapors from the exhaust stream, and it is typically backed up with another emission control such as carbon adsorption.

Carbon adsorption uses granular activated carbon to absorb contaminant vapors. Two types of carbon adsorption systems are available. The first uses disposable carbon, which is discarded when saturated with organic compounds. The second reclaims the carbon using steam stripping to volatilize the contaminants and strip them from the carbon. The steam is then condensed and the immiscible organic products are separated from the water. Carbon adsorption is discussed in more detail in Section 2.2.

Incineration, which is discussed in other sections in this manual, is applicable to large venting projects which produce substantial quantities of organics, or where incineration is a concurrent treatment. In the latter case, the vented gas can be used as make-up air to the combustion chamber. When properly operated, incineration is the most efficient technique for treating hydrocarbon emissions.

2.4 SOILS HANDLING

Remedial actions at NPL sites will very often involve handling of contaminated soil. This handling may result in fugitive dust emission that can carry inorganic and organic constituents which are contained in, or are adhering to, the dust particles. Soils handling can also lead to enhancement of volatile organic emissions due to exposure of the contaminated soil to the atmosphere. Specific activities with emission potential include excavation, transport, dumping, storage, or grading.

This section addresses particulate and volatile organic emissions from area-wide sources of fugitive emissions such as soils handling activities. The discussion applies to any underlying, concentrated wastes as well as to contaminated soils themselves. Stabilization and solidification are remedial actions that are likely to involve the soil handling activities discussed in this section, but also involve other unique soil processing steps. Stabilization and solidification are covered separately in Section 2.5.

2.4.1 Emission Sources

Remedial activity at Superfund sites can produce air quality impacts from the handling of contaminated soil, and this is one of the major types of waste (by volume) handled during a typical remedial action. Digging and relocating of soil causes fugitive dust emissions and enhances volatilization of organic compounds to the atmosphere. Through entrainment in wind, fugitive particulates and organic compounds can be carried great distances away from the site. Contaminated soil particles may also carry trace metals and organics which have been adsorbed onto the particle surface.

It is important to discern which of the remedial operations have a significant potential for air emissions, to quantify these emissions if possible, to weigh possible treatment alternatives with potential air hazards, and to control these emissions when necessary. To this end, the various possible steps in soils handling during remedial treatment have been divided into five broad categories: excavation, transport, dumping, storage, and grading.

Excavation is the process of digging up contaminated soil and waste from the dump. Common types of equipment used for excavation are backhoes, draglines, bulldozers, front-end loaders, scrapers, etc. The machinery is described in detail in an EPA handbook (26). Soil is stirred by the excavation equipment and contributes to fugitive particulate emissions. Exposure of the wastes to the atmosphere due to removal of the soil covering can also increase volatile organic emissions from the site.

Transport in this report refers to travel of trucks between and around storage piles, as well as travel on paved and unpaved roads. Unless the wastes are transported to another site for disposal, incineration, or other remedial treatment, the fugitive dust emissions from travel on paved and unpaved roads are expected to provide only a minor contribution to the overall emission factor. Travel between, around, or on piles may present the more serious emission problem because of the possibility of workers being exposed to adsorbed contaminants on the particulate and the possibility of wind entrainment. For long-distance transport, effective, inexpensive emission controls are available.

Dumping of soil as a part of remedial action refers to both dumping from excavating machinery into trucks and dumping from trucks onto storage piles. Again, fugitive particulate emissions and volatilization will usually be the main concerns. Storage in piles presents opportunity for fugitive emissions through wind erosion and entrainment of particulate.

Grading refers to the leveling technique applied to the waste site after remedial action has been completed. Usually, a tractor or dozer fitted with a blade is used for this, although at some sites pan scrapers or motor graders are used (27).

Typical ranges of particulate matter emissions for handling of contaminated soil are shown in Table 10. Estimated contributions of the more common activities, expressed as percentages of overall fugitive dust emissions, are as follows (28):

• Loading onto piles (dumping)	12%
• Equipment and vehicle movement (excav. and trans.)	40%
• Wind erosion (storing)	33%
• Loadout from piles (dumping)	15%

The contributions are estimated with data from the crushed rock industry.

2.4.2 Key Parameters Affecting Emissions

Fugitive dust is usually the most ubiquitous type of emission from remedial action, but depending on the waste present at the site, increased amounts of volatile organic compounds (VOs) can escape into the air when the wastes and soil covering are disturbed. Wind entrainment can carry the particulates away from the site.

Theoretical drift distances, as a function of particle diameter and mean wind speed, have been computed for fugitive dust emissions. Many of the emission factors and equations obtained from USEPA (31) are given as a function of particulate diameter to allow the computation of emissions in the size range of interest. Large particles with diameters greater than 100 microns (um) are likely to settle within 5 to 10 meters of the emissions source. Those which are 30 to 100 microns in diameter are likely to settle within a hundred meters or so of the source, except in cases of high atmospheric turbulence. Smaller particles, especially those with diameters less than 10 to 15 microns, are much more likely to stay adrift in the atmosphere because of turbulence (32). Particles smaller than 10 to 15 microns are considered to be respirable; i.e., they can enter and lodge in human lungs (26).

TABLE 10. TYPICAL RANGES OF EMISSION FACTORS

Activity	Particulate Matter[a]	Notes	Reference
Excavation	0.002-0.086 kg/metric ton 0.015-0.22 kg/metric ton	Overburden Topsoil	29,30 31,32
Transport:			
Unpaved Roads	1.3 kg/VKT	Estimated from equation	-
Dry Industrial Paved Roads	0.022-0.15 kg/VKT	Medium & heavy vehicles	31
Heavily-loaded Industrial Roads	0.093-0.12 kg/VKT	Light duty vehicles	31
Dumping	0.005-0.05 kg/metric ton 0.015-0.03 kg/metric ton 0.025-0.16 kg/metric ton	Continuous Batch Diatomite	33 31 30
Storage:			
Inactive Piles	0.39 g/m^2/day, 0.055 kg/metric ton	Wind erosion only	28
Active Piles	1.5 g/m^2/day, 0.21 kg/metric ton	8-12 hrs/day activity	28
Active/Inactive Piles	1.2 g/m^2/day, 0.16 kg/metric ton	5 active days/week	28
Grading	0.006 kg/metric ton	Overburden replacement	31
TSP	5.4 kg/hr	Grading spent diatomite	30
15 to 25 um	2.5 kg/hr	Grading spent diatomite	30
<2.5 um	0.03 kg/hr	Grading spent diatomite	30
<15 um	2.6 kg/hr	Grading spent diatomite	30

[a] Units are kilograms per metric ton of soil moved, kilograms of emissions per vehicle kilometer traveled (VKT), grams of emissions per square meter of storage pile surface area per day, or kilograms of emissions per hour of grading.

Organics and trace metals may also migrate or diffuse from the underlying waste into the soil covering and adsorb onto soil particles. When present on respirable particles, the metals or organics could enter the bloodstream through the lungs and present additional health hazards.

For these reasons, site-specific information on the composition of the waste present is important, particularly concentrations of organic compounds and metals. At the same time, the emissions are also dependent on other parameters in addition to the waste composition. For example, meteorological conditions (e.g., wind speed, prevailing wind direction, amount of precipitation), the amount of activity (e.g., excavation, dumping, storing in piles), and soil/waste physical properties (e.g., silt content) must be considered.

Table 11 contains a list of parameters that may effect the emissions potential at a given site. Meteorological data can be obtained from a local office of the National Weather Service. Operating characteristics of the remedial activity are site-dependent and may be obtained through on-site observation or from vendors and/or operators. Soil and waste characteristics may be obtained from the remedial investigation for the site or from the Soil Conservation Service. A few of the more important physical properties are discussed in the following paragraphs. The dependence of air emissions on these parameters is addressed in Section 3.6.

Silt content is defined as the weight fraction of the soil passing through a 200-mesh screen, i.e., that which is less than 75 microns (um). The PM-10 portion is the weight fraction of the silt with a physical diameter (not aerodynamic diameter) of less than 10 microns (um). Percent moisture is determined by gravimetric analysis, measured by the weight loss of the sample after oven drying (27).

TABLE 11. IMPORTANT PARAMETERS IN DETERMINING AND CONTROLLING EMISSIONS FROM SOILS HANDLING

	Typical Importance to Emission Level	
Parameter	Particulates/Metals	Volatile Organics
Meteorological Conditions		
Wind Speed	Medium	Medium
Wind Direction/Variability	Low	Low
Temperature	Low	Medium
Relative Humidity	Low	Low
Barometric Pressure	Low	Low
Precipitation	High	Medium
Solar Radiation	Low	Low
Operating Characteristics		
Area of Working Face	Medium	High
Agitation Factor	High	High
Drop Height	Low	Low
Storage Pile Geometry	Medium	Low
Available Soil Cover	High	High
Soil/Waste Characteristics		
Physical Properties		
Silt Content	High	Low
PM-10 Content	Low	Low
Density	Low	Medium
Permeability	Low	High
Moisture Content	High	Medium
Organic Fraction	Low	High
Metal Concentrations	High	Low

The rationale for measuring the PM-10 parameter is the hypothesis that the hazardous constituents (e.g., heavy metals) in the contaminated soil or surface material may tend to absorb preferentially on finer particles. The finer particles are thought to remain airborne for longer periods of time, and they may therefore be transported considerable distances from the site (27).

2.4.3 Possible Control Technologies

Measures to control fugitive particulate and volatile organic emissions are available for remedial action applications. Conventional techniques include water sprays, surfactants or "wetting agents", dust suppressants, windscreens, and slope and orientation of storage piles. New technologies are also being developed and tested on smaller scales, but they have not yet been accepted as conventional practices. These measures include temporary and stabilized foams, membrane coverings, spray charging and trapping systems, and road carpets. Each technology will briefly be discussed in the following paragraphs. Table 12 shows the control technologies which may be applied to each of the emission categories discussed previously.

The most common method of dust control at hazardous waste sites is the use of water sprays. Surface wetting also inhibits volatilization by filling available pore spaces with water and thereby decreasing diffusion rates. This usually entails spraying the active working area (34), a process which has to be repeated about every two hours to maintain effectiveness (26). Another approach is to spray a curtain which would totally cover the bed or box of a dump truck. This method has been tested by Rosbury and James (34). One test was done with a continuously sprayed curtain; in another test, a foaming agent was added to an intermittent water spray, where the spray was only activated during the dump from an excavator into a truck box. Control efficiencies for these and other technologies and applications are shown in Table 13. Potential concerns with surface wetting are flushing contamination down into ground water and run-off to surface waters. When surface wetting at

TABLE 12. CONTROL TECHNOLOGIES AVAILABLE FOR EACH SOILS HANDLING EMISSION CATEGORY

Excavation	Water sprays of active areas Dust suppressants Surfactants Foam coverings
Transportation	Water sprays of active areas Dust suppressants Surfactants Road carpets Road oiling Speed reduction Coverings for loads
Dumping	Water sprays of active areas Water spray curtains over bed during dumping Dust suppressants Surfactants Enclosure of dumping area for material transfer
Storage	Windscreens and other enclosures Orientation of pile Slope of pile Foam covering and other coverings Dust suppressants
Grading	Light water sprays Surfactants

TABLE 13. EFFICIENCIES OF VARIOUS CONTROL TECHNOLOGIES

Application	Dust Control Efficiency Percent		Vapor Control Efficiency (%)	Dosage (L/m^2)	Reference
	TSP (<30 um)	FP (<2.5 um)			
Spray of Active Excavation Area, Front End Loader:					
Water Spray	42	64	NA	4.1	34
Water + Surfactant	63	70	NA	3.4	34
Spray of Dumping Area, Front End Loader to Truck:					
Area Spray - Water	69	66	NA	4.1	34
Area Spray - Water + Surfactant	77	62	NA	4.1	34
Water Curtain (continuous)	50	56	NA	6.8	34
Foam Curtain (intermittent)	46	41	NA	1.8	34
Dust Suppressant					
Unpaved Road	40-99	20-95	NA	Variable	35
Wastepile	50-70	NA	NA	Variable	36
Windscreens					
Coal Pile	45-65	NA	NA	-	37
"Beehive"-Type Enclosures for Storage Piles	100	NA	NA	-	36
Orientation of Storage Pile Length Perpendicular to Prevailing Wind	60	NA	NA	-	36
Synthetic Covers					
Temporary Foam (20 minutes)	NA	NA	81	6/94*	38
Stabilized Foam (24 hours)	NA	NA	99	6/94*	38,39,40
Rigid Foam (2 hours)	NA	NA	73	NA	40

NA = not available.
- = not applicable.
* First number is percent foam concentrate; second number is percent water.

a hazardous waste site is being considered, the potential impact on surface and ground waters as well as the potential benefit of reduced air emissions should be considered.

Control efficiencies were measured for each of the water spray tests performed by Rosbury and James (34). For the simple water spray of the active working area, control efficiencies were 66-69% for the dumping area and 42% for the travel and scraping area (excavation). It should be noted that the ground was sprayed only twice a day during the testing. Also, the control efficiencies are for total suspended particulate (TSP), which includes all particles with less than a 30 micron diameter. Water sprays on the travel and scraping areas showed a 64% control efficiency during the study for fine particulates (FP, with less than a 2.5 micron diameter).

When the dump truck box was sprayed with a continuous stream of water, the control efficiency was 50% for TSP and 56% for FP. The author noted that continuous spray could probably be replaced with intermittent spray during dumping without a significant loss of control efficiency. Intermittent spray was tested with a foaming additive. The calculated control efficiency for that test averaged 46% for TSP and 41% for FP.

Chemical dust suppressants are sometimes used in conjunction with water sprays for added control effectiveness. The purpose of dust suppressants is to strengthen the bonds between soil particles. Their effectiveness is dependent on maintaining an undisturbed soil-chemical crust. Vegetation and traffic will break the crust and require more frequent applications (26).

Several types of chemicals are available on the market. Surfactants or surface wetting agents are also available. More detailed discussions, complete with control effectiveness, recommended doses, and cost of the dust suppressants and surfactants have been published (26,28,41). Rosbury and James (34) tested the effectiveness of spraying the active working area with a water spray containing a surfactant. The control efficiency in the travel and scraping area was 63% for TSP and 70% for FP. When tested in the dumping area, the control efficiency averaged 77% for TSP and 62% for FP.

Water sprays, surfactants, and dust suppressants may be used to control emissions from unpaved roads. Other available means of control include oiling of roads (29), reduction of vehicle speed, and covering the load with a tarp or other means of containment. The latter can be particularly important in reducing emissions during long-distance transportation, especially at high speeds.

Another type of control for fugitive particulate emissions is to enclose the active area or storage piles with supported structures, such as windscreens (26,37). Porous screens or other structures are designed to deflect enough wind to lower the wind velocity below the threshold required to stir soil. Windscreens are a mobile, low-cost method of reducing fugitive particulate emissions. However, wind speed reduction is practical only when the source is small (33).

Several studies have been performed to determine the control efficiency of windscreens. At best, they are only partially effective in controlling inhalable particulates (26), which are those particles with a diameter less than 15 microns (41). Control efficiencies of about 60% for inhalable particulate and 75% for TSP have been reported with wind speeds of 4.4 to 5.8 meters/sec (10 to 13 mph) and gusts of 8 to 8.5 meters/sec (18 or 19 mph). In another study, the results showed some effectiveness with particles larger than inhalable particulate, but no consistent benefits were apparent for particles in the 10-micron size range. The results of both studies were summarized in USEPA (26).

A secondary form of wind-blown particulate control lies in the slope and orientation of the storage pile. Keeping the slope of the pile less than 10 degrees in the direction of prevailing winds will help minimize emissions. Also, if the long side of a pile is perpendicular to the prevailing wind, emissions can be reduced by about 60% (36).

Several new technologies also exist: spray foam coverings, synthetic membranes, spray charging and trapping, and road carpets (36,38,39,40,41,42). The term "new" does not necessarily mean that these technologies have not been tried or tested, but that they have not yet been accepted into conventional practice at hazardous waste sites for control of fugitive particulate or volatile organic emissions. The technologies are discussed in the following paragraphs. When available, control efficiency data are included in Table 13.

Two types of foam coverings have been developed: temporary and stabilized foams. Temporary foam is a slow-draining fluid foam with approximately a 30-minute lifetime. It is usually used when immediate but short vapor suppression is required, such as during excavation or dumping of wastes. Stabilized foam, on the other hand, hardens 1-4 minutes after spraying into a tough, elastic, nondraining surface cover. The stabilized foam lasts as an effective vapor suppressant for about 24 hours. After several days, the foam will dehydrate and collapse into an elastic membrane. The aged foam seemed to consolidate particles very effectively, which should reduce airborne particulate (38).

Both temporary and stabilized foams can be used during excavation at active sites as vapor and dust-suppressive coverings (38,39,40). The foams are environmentally compatible (39) and have been tested at several sites under varying conditions, including an underground burning landfill (38), a petroleum waste site (38,39), a floating roof petroleum storage tank (39), sour refinery water (39), and acid fumes from a thin spill of oleum (39).

Membranes of the type used to control volatile emissions from land treatment areas and surface impoundments have been considered for use at remedial action sites. However, the cover would probably be punctured or torn by equipment as waste is excavated from the site (36). Therefore, membranes such as neoprene and polyvinyl chloride are probably not the most cost-effective control alternative. Also, many membranes show poor performance for retaining organic compounds from landfills or surface impoundments (36). Results from control tests of volatile organics with polyvinyl chloride membranes have reportedly been disappointing (42).

The Spray Charging and Trapping (SCAT) system controls fugitive particulates by diverting them into a charged spray scrubber located near the emissions source. Different designs to accomplish this task are being considered; one possibility is to use one or more high-velocity air streams, produced by air jets, to entrain particulates and push them away from the source. Downstream, a charged stream of water or an aqueous compound is sprayed concurrently into the gas stream to remove the entrained dust. After sufficient contacting time to allow capture of most of the gas stream particles, a low-pressure drop entrainment separator is used to separate the water spray drops from the gas stream. A system prototype has so far been tested in cross-wind conditions and on a hot, buoyant plume of smoke (41).

Road carpets are fabrics which have been developed to stabilize and contain particulates on unpaved roads, or surfaces such as those around storage piles which are exposed to excessive traffic. Road carpets help to spread the concentrated stress from heavy-wheeled traffic over a wide area, siphon away groundwater, and contain fine soil particles (41).

Studies have shown that for unpaved road, application of a road carpet material is not as cost effective as paving; however, a road constructed with fabric is less expensive than one that has to be continually watered (41). Road carpets may therefore be a possible control measure for use around storage piles, or for sections of the remedial action site which receive heavy traffic, but are otherwise not disturbed (e.g., excavated).

2.5 STABILIZATION/SOLIDIFICATION

Stabilization/solidification differs from the soils handling steps described above in that it is a treatment technology. It is more complex and more costly than the other types of soils handling operations. Several types of stabilization and solidification processes exist as alternatives for remedial action (43,44). Cost information for these processes may be found in Cullinane (43). Except for emerging technologies that involve in-situ treatment, the implementation of stabilization of solidification generally involves several of the soil handling activities previously discussed. Thus, consideration of emissions from stabilization or solidification must generally address both the emissions that result directly from the treatment process and the emissions from the associated soils handling activities.

Stabilization/solidification (encapsulation) processes are currently being developed and evaluated for hazardous waste applications. Due to the rapidly evolving nature of this technology, the material presented here is preliminary and subject to revision.

2.5.1 Emission Sources

Stabilization processes reduce the hazard potential of a waste by converting it to its least soluble, mobile, or toxic form. The physical nature or handling characteristics of the waste are not necessarily changed by the technique. Solidification processes (sometimes called encapsulation processes) bind the waste in a structurally sound, uniform solid (43).

The basic steps in solidification and stabilization processes are generally the same: wastes are loaded into the mix bin (wastes are sometimes dried before addition to the bin), and other materials for the solidification or stabilization are added. The contents of the bin are mixed and removed from the bin (27,43). It is important to note that these basic steps describe batch or continuous treatment of soil after it has been removed from its original location. True in-situ treatment methods, such as vitrification by applied voltage or injection of stabilizing agents are emerging technologies.

Many of the processes and materials are in common use, though not necessarily at remedial action sites. The thermoplastic microencapsulation process, for instance, was originally developed for disposal of radioactive waste (43). Typical raw materials used in stabilization processes (43,44) are fly ash, cement kiln dust, lime kiln dust, or hydrated lime. Typical binding agents for solidification/encapsulation processes are asphalt, paraffin, polyethylene, or polypropylene.

It is important that the waste not react with the stabilizing or binding agents in a way that interferes with the solidification process. Because of this restraint, the maximum organic chemical content of aqueous wastes that can be solidified using cement is 2-3 percent (36). And, since solidification processes usually require heating during the mixing step, they are usually not suitable for combustible materials such as solid hydrocarbons or sulfur, since the mixture can ignite at the elevated temperatures (120 to 260°C).

Possible sources of fugitive dust emissions from stabilization and solidification processes are storage of raw materials, preparation of the stabilization or binding agents, the dumping of wastes into the mixing bin, removal of the material from the mixing bin, and replacement of the material at the site after processing. The emissions data shown in Table 8 are not from actual solidification or stabilization processes, but were taken instead from the concrete batching and asphaltic concrete production industries, respectively. Neither extraction or replacement are included in the Table 8 estimates, so emissions for these activities must also be added to obtain an overall estimate.

Organics present in the wastes may be volatilized during the solidification or stabilization processes. However, very little information exists about the fate of the volatile constituents during these processes.

Typical ranges of particulate matter emissions for stabilization/ solidification are shown in Table 14. Very little data exist for VO emissions from these processes. VO emissions from stabilization at the Kettleman Hills waste facility have been estimated to be 5000 kg per year (45).

2.5.2 Key Parameters Affecting Emissions

The key parameters affecting PM and VO emissions are listed in Table 15. The effects of most parameters were discussed in the previous section on soils handling. Indeed, much of Table 15 is identical to Table 11. The differences relate to the effects of operating characteristics as discussed below.

In general, VO emissions will depend on the duration and thoroughness of the mixing, the amount of heat generated in the process, and the average batch size. The longer or more energetic the mixing and processing, the greater likelihood that organic compounds will volatilize. The volatile losses will also increase as the temperature of the waste/binder mixture increases. Binding agents with high lime contents generally cause highly exothermic reactions. The batch size affects volatilization by affecting the mean distance a volatilized molecule has to travel to reach the air/solid interface at the surface of the stabilized waste. The larger the block of material, the lower the rate of volatilization.

Particulate matter emissions from stabilization are usually not significant relative to the emissions from handling the material.

2.5.3 Possible Control Technologies

Possible control technologies for stabilization/solidification of hazardous wastes are listed in Table 16. Emissions controls generally require enclosing the work areas to minimize air movement and subsequent windborne losses. Venting of such enclosures using a baghouse with fabric filters to collect the particulate matter may be necessary to avoid restrictive safety requirements for workers in the enclosure.

TABLE 14. TYPICAL RANGES OF EMISSION FACTORS

Activity	Particulate Matter[a]	Notes	Reference
Stabilization/Solidification/ Encapsulation[b]	0.27 kg/m^2/month	Heavy construction	31
Stabilization[c]	0.31 kg/metric ton	Concrete batching	28,29
Solidification/Encapsulation[c]	0.41 kg/metric ton	Asphaltic concrete production	28,29
Replacement (for Stab/Solid)	0.006 kg/metric ton	Overburden	31

[a] Units are kilgrams of emissions per square meter of the soil surface area being processed per month, or kilograms of emissions per metric ton of soil processed.

[b] Includes excavation, transportation, dumping, replacement--rough estimate only.

[c] Does not include excavation of material or replacement of material back at waste site; does include storage and traffic between piles and processing plant.

TABLE 15. IMPORTANT PARAMETERS IN DETERMINING AND CONTROLLING EMISSIONS FROM STABILIZATION AND SOLIDIFICATION

	Typical Importance to Emission Level	
Parameter	Particulates/Metals	Volatile Organics
Meteorological Conditions		
Wind Speed	Medium	Medium
Wind Direction/Variability	Low	Low
Temperature	Low	Medium
Relative Humidity	Low	Low
Barometric Pressure	Low	Low
Precipitation	High	Medium
Solar Radiation	Low	Low
Operating Characteristics		
Binder Type	Medium	High
Batch Size	Low	Medium
Waste/Binding Agent Ratio	Medium	Medium
Mixing Time/Efficiency	Low	High
Curing Time	Low	Low
Soil/Waste Characteristics		
Physical Properties		
Silt Content	High	Low
PM-10 Content	Low	Low
Density	Low	Medium
Permeability	Low	High
Moisture Content	High	High
Organic Fraction	Low	High
Metal Concentrations	High	Low

TABLE 16. CONTROL TECHNOLOGIES FOR STABILIZATION AND SOLIDIFICATION

Remedial Operation	Control Technology
Mixing Area/Apparatus	Enclosure Venting of enclosures to fabric filter
Binder Preparation	Enclosure of binder preparation area
Raw Material Storage	Storage pile controls
In-Situ Treatment	Suction hood

SECTION 3

PROTOCOL FOR ESTIMATING EMISSIONS

This section presents a step-by-step protocol and associated equations for estimating emissions from a variety of remedial operations during the clean-up of Superfund (NPL) sites. The protocol is designed to allow the user to make relative comparisons of the impacts on air quality from remedial options being considered for implementation. Guidance on the types of available control technologies for reducing air emissions and their typical effectiveness are also presented.

The protocol is graphically presented in Section 3.1. A preliminary screening approach for estimating emissions from a site is given in Section 3.2. The remaining subsections present equations and input values for each specific remediation option considered in this manual.

3.1 PRESENTATION OF PROTOCOL STEPS

Estimating emissions is the focus of this manual, but it is only one element of an air pathway analysis. Any emission estimate must also be evaluated for its impact on potential receptors. A flow chart showing the basic elements of an air pathway analysis is given as Figure 9. An explanation of each step is beyond the scope of this manual; however, Volume I of this series of manuals (1) does provide such an explanation. Also, a brief description of each element is given in Appendix D of this manual.

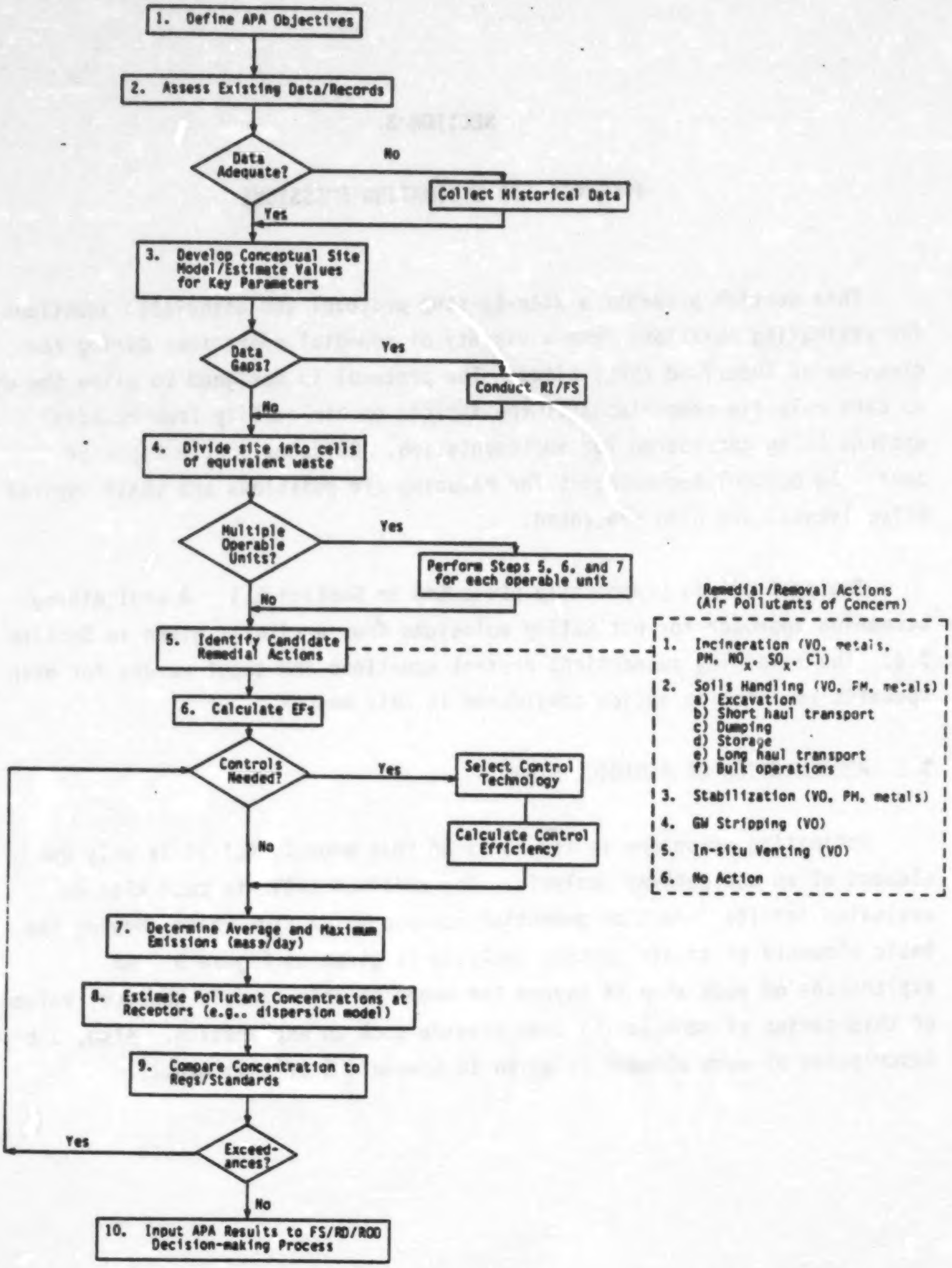

1. Define APA Objectives
2. Assess Existing Data/Records
Data Adequate?
No
Collect Historical Data
Yes
3. Develop Conceptual Site Model/Estimate Values for Key Parameters
Data Gaps?
Yes
Conduct RI/FS
No
4. Divide site into cells of equivalent waste
Multiple Operable Units?
Yes
Perform Steps 5, 6, and 7 for each operable unit
No
5. Identify Candidate Remedial Actions
Remedial/Removal Actions (Air Pollutants of Concern)
1. Incineration (VO, metals, PM, NOx, SOx, Cl)
2. Soils Handling (VO, PM, metals)
a) Excavation
b) Short haul transport
c) Dumping
d) Storage
e) Long haul transport
f) Bulk operations
3. Stabilization (VO, PM, metals)
4. GW Stripping (VO)
5. In-situ Venting (VO)
6. No Action
6. Calculate EFs
Controls Needed?
Yes
Select Control Technology
Calculate Control Efficiency
No
7. Determine Average and Maximum Emissions (mass/day)
8. Estimate Pollutant Concentrations at Receptors (e.g., dispersion model)
9. Compare Concentration to Regs/Standards
Exceedances?
Yes
No
10. Input APA Results to FS/RD/ROD Decision-making Process

Figure 9. Flow chart of air pathway analysis for remediation

3.2 PRELIMINARY EMISSIONS ESTIMATION PROCEDURE

This subsection presents a simple procedure for making a gross estimate of emissions due to remedial activities. It is intended to be used as a screening tool to assess whether emissions from remediation may be significant at a given site, using a given remedial technology. Sites that have the potential for significant emissions, based on this screening, should have their emissions potential subsequently evaluated using the more precise estimation procedures for each remedial technology given in the following subsections. The screening procedure is necessarily conservative, i.e., sites with any likelihood of significant emissions are referred to the more precise, but more time consuming, estimation procedures.

The necessity of evaluating air emissions for a given site is dependent on the type of hazardous material(s) at the site, the size of the site, and the proposed treatment options. The following information should be known to initially assess the emissions potential of the site:

- Estimate the volume (m^3), mass (kg), and type of waste material to be treated;

- Estimate the concentration of VOCs, heavy metals, dioxins, asbestos, and pesticides in the waste material (ug/g);

- List the probable treatment options and control technologies; and

- Estimate the operating rate for remedial activities.

Table 17 lists remedial options and their associated control technologies. Typical operational rates and air emission values for various remedial options are presented in Table 18.

TABLE 17. CONTROL TECHNOLOGIES AVAILABLE FOR EACH REMEDIAL OPTION

Remedial Operation	Contaminant	Control Technology
Incineration	Hydrocarbons	Afterburner, Operational (in-furnace) methods
	Particulate	Venturi scrubber, Electrostatic precipitator, Ionizing wet scrubber, Fabric filter (baghouse)
	Acid Gases	Spray dryers, ionizing wet scrubber, venturi scrubber
	NO_x	Catalytic reduction, Operational (in-furnace) methods
	Fugitives	Inspection/maintenance
Ground Water Stripping	Hydrocarbons	Condensation Carbon adsorption (disposable) Carbon adsorption (regenerable) Incineration
In-situ Venting	Hydrocarbons	Condensation Carbon adsorption (disposable) Carbon adsorption (regenerable) Incineration
Soils Handling		
Excavation	Particulates, Hydrocarbons	Water sprays of active areas Dust suppressants Surfactants Foam coverings
Transportation	Particulates, Hydrocarbons	Water sprays of active areas Dust suppressants Surfactants Road carpets Road oiling Speed reduction Coverings for loads
Dumping	Particulates, Hydrocarbons	Water sprays of active areas Water spray curtains over bed during dumping Dust suppressants Surfactants

(Continued)

TABLE 17. (Continued)

Remedial Operation	Contaminant	Control Technology
Soils Handling (Cont.)		
Storage	Particulates, Hydrocarbons	Windscreens and other enclosures Orientation of pile Slope of pile Foam covering and other coverings Dust suppressants
Grading	Particulates, Hydrocarbons	Light water sprays Surfactants
Stabilization/ Solidification	Particulates, Hydrocarbons	Enclosure of mixing area/apparatus Storage pile controls for raw materials Enclosure of binder preparation area Suction hood (in-situ treatment)

TABLE 18. SUMMARY OF TYPICAL AIR EMISSION VALUES BY SOURCE TYPE

Remedial Option	Typical Operation Rate	Uncontrolled Emissions		Controlled Emissions	
		PM	VOC	PM	VOC
Incineration	650 m^3/min[a] 50,000,000 BTU/hr	0.5-23 g/m^3	0.1-500 ug/m^3	34-110 mg/m^3	-
Air Stripping	3500 L/min	0	5-50 kg/day[b]	0	50-100 ppm[c]
In-situ Ventilation	0.15-0.85 m^3/min[d]	0	1-110 kg/day	0	50-100 ppm[c]
Excavation					
Backhoe	900 m^3/day	0.002-0.22 kg/ metric ton	-	-[e]	-
Dragline	700 m^3/day	-	-	-	-
Scraper	340-610 m^3/day	-	-	-	-
Bulldozer	1100 m^3/day	-	-	-	-
Grading	-	0.03-5.4 kg/hr	-	-[e]	-
Transport					
Unpaved Roads	5 trucks/hr	1.3 kg/VKT	-	-[e]	-
Paved Roads	5 trucks/hr	0.022-0.15 kg/ VKT	-	-[e]	-
Dumping	24-270 m^3/day	0.005-0.16 kg/ metric ton	-	-[e]	-
Storage	-	0.39-1.5 g/m^2/ day	-	-[e]	-
Stabilization	-	0.31-0.41 kg/ metric ton	-	-[e]	-

[a] Exhaust gas rate.
[b] Assume 1-10 mg/L pollutant.
[c] 95-99% efficiency for gas streams of 1000-10,000 ppm VO. Multiple treatment units may feed a single control system.
[d] Exhaust gas rate per recovery well.
[e] Assume control efficiency of 50%.
Note: "-" implies insufficient data to generate typical value.

No clear-cut rules-of-thumb exist for screening which remedial actions are likely to have significant emissions and which remedial actions are not. Only a quantitative evaluation of emissions and their impacts can show the significance of a remedial action. Nevertheless, considerations based on common sense may be used to make qualitative judgments of potential significance. If any of the conditions below are met, then a more rigorous review is recommended.

1. Off-site receptors are near (e.g., within 1 km) of the emission source.
2. The contamination includes any volume of dioxins or areas containing highly concentrated pesticides, volatile carcinogens, or asbestos, and the material will be handled or exposed.
3. The total contamination (mass x concentration) of pesticides, toxic metals, volatile carcinogens, or asbestos at the site is substantial (e.g., exceeds 100kg), and this material will be handled or exposed.
4. The total contamination (mass x concentration) of VOCs at the site is substantial (e.g., exceeds 1,000 kg VOCs), and this material will be handled or exposed.
5. Volatile organic contaminants are to be treated by incineration, groundwater stripping, or in-situ ventilation, and no emissions controls are to be used.
6. There is reason to believe that the control technology will not be effective for some toxic compounds present in the waste.
7. The anticipated operating rate is relatively large (e.g., >10 times the values given in Table 18).

Note that sites with insignificant impacts on any off-site areas may still have an impact on the health and safety of on-site workers, and appropriate precautions should be followed. For sites that are judged to warrant a full evaluation, Figure 9 suggests the components that such evaluations should have, and subsequent subsections describe procedures for making detailed emissions estimates.

3.3 ESTIMATION OF EMISSIONS FOR THERMAL DESTRUCTION DEVICES

As discussed in Section 2, a variety of thermal destruction devices exist. Incinerators are by far the best known and most studied type of thermal destruction devices. Other types of thermal destruction devices must in most cases be assumed to have similar emissions characteristics as incinerators.

Thermal destruction of wastes from NPL sites generally must meet requirements of RCRA since these are generally considered applicable or relevant and appropriate requirements (ARARs). The most prominent of these requirements is a mandate that the principal organic hazardous components be 99.99% destroyed or removed. Additional requirements dictate a limit on particulate emissions of 180 mg/standard m^3 (0.08 grains/standard ft^3). Similarly, for wastes containing dioxins or polychlorinated biphenyls (PCBs), TSCA requirements generally apply that dictate a destruction and removal efficiency of 99.9999% of these pollutants.

A default approach to estimating emissions from thermal destruction of hazardous waste is to assume that the above requirements of RCRA and TSCA will be exactly met. If emissions are to be estimated in a feasibility study or otherwise prior to incinerator design, then this default approach may be the only option for estimating emissions. After the incinerator is designed, three additional options for evaluating actual emissions more precisely may be available. The first and most rigorous method for emissions estimation would be to perform a trial burn on the waste in question or a similar waste and sample the influent and effluent streams for the pollutant of concern. Where this is not technically or economically feasible, a second approach using theoretical or empirical equations correlating incinerator operating parameters to pollutant emission rates is desirable. In the absence of applicable correlations, a third approach is to use data accumulated from the various trial burns that have been conducted, and assume the results are applicable to the site in question.

This section attempts to provide either correlations or typical data to allow estimation of pollutant emissions from incinerator operations. This section also provides information to assist evaluation of whether specific designs are likely to meet RCRA or TSCA requirements. Figure 10 is a flowchart delineating the sequence of steps by which emissions for a incineration of a given waste may be estimated. Estimation methods are provided for various types of emissions including: organic compounds, metals/particulate matter, HCl, SO_2, HF, NOx, and fugitive emissions. The general form of the emissions estimation equations are given in Table 19.

3.3.1 Organic Compounds

The incinerator flue gas emissions of organic compounds is a function of the destruction and removal efficiency (DRE) of the system. Currently, no models exist for calculating the DRE for incineration of hazardous wastes. This is a due to several factors including the complex nature of the chemical reactions taking place in an incinerator; the great diversity of wastes, each with unique chemical and physical characteristics; and the variety of incinerator types and operating methods.

Since 1981, EPA has evaluated the emissions from a large number and variety of incineration facilities. Evaluation of data taken from these studies indicate that virtually any properly designed and operated incineration unit should be able to achieve at least 99.99% DRE for the organic compounds present in the waste (6,7,9). Sufficient temperature, retention time, oxygen, and feed control are necessary for high destruction. Use of Tables 2 and 5 provide preliminary guidance for the selection of incinerator type, residence time, and operating temperatures to maximize destruction of the organic constituents in the waste.

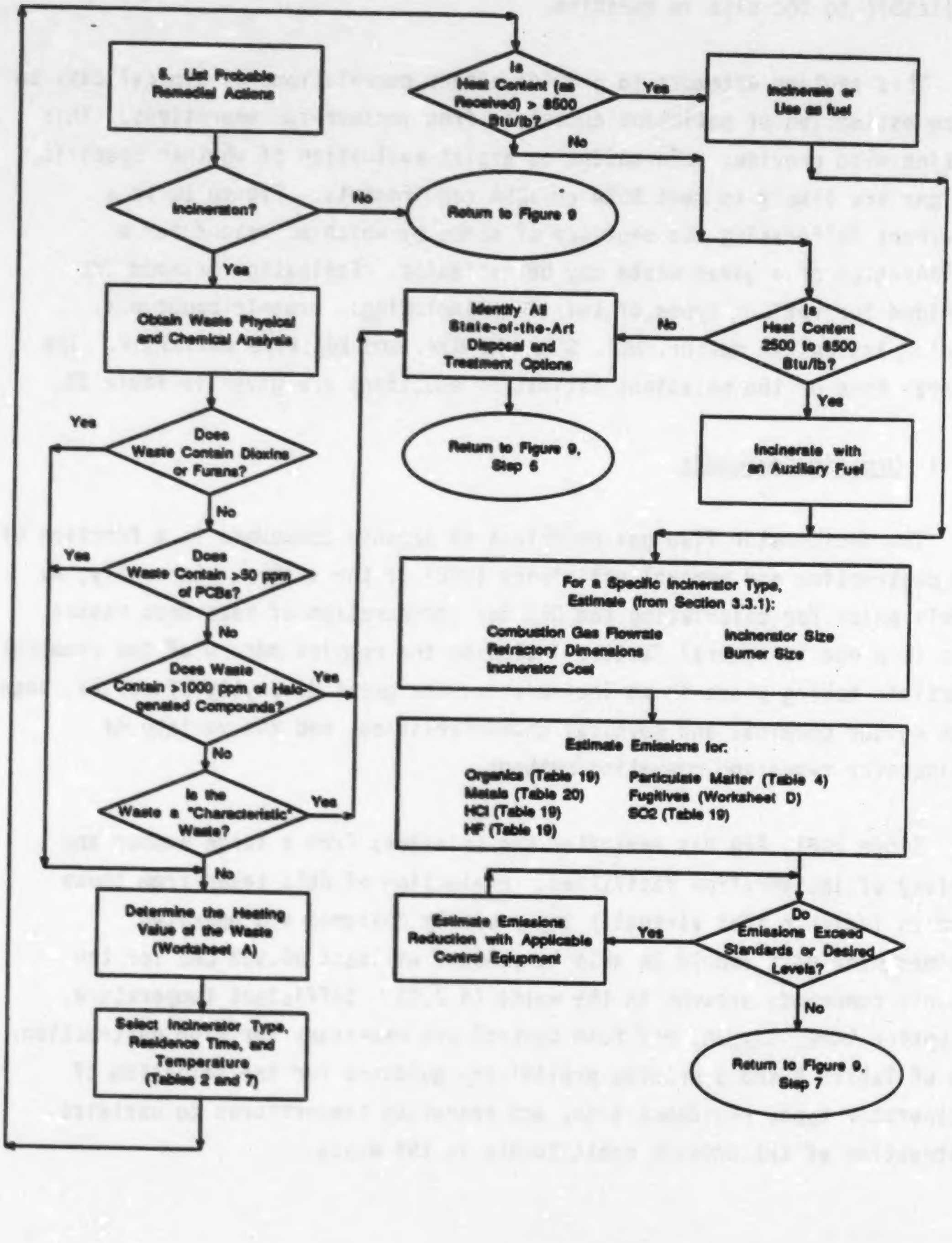

5. List Probable Remedial Actions
Incineration?
No
Return to Figure 9
Yes
Obtain Waste Physical and Chemical Analysis
Does Waste Contain Dioxins or Furans?
Yes
No
Does Waste Contain >50 ppm of PCBs?
Yes
No
Does Waste Contain >1000 ppm of Halogenated Compounds?
Yes
No
Is the Waste a "Characteristic" Waste?
Yes
No
Determine the Heating Value of the Waste (Worksheet A)
Select Incinerator Type, Residence Time, and Temperature (Tables 2 and 7)
Is Heat Content (as Received) > 8500 Btu/lb?
Yes
Incinerate or Use as fuel
No
Is Heat Content 2500 to 8500 Btu/lb?
No
Identify All State-of-the-Art Disposal and Treatment Options
Return to Figure 9, Step 6
Yes
Incinerate with an Auxiliary Fuel
For a Specific Incinerator Type, Estimate (from Section 3.3.1):
Combustion Gas Flowrate
Refractory Dimensions
Incinerator Cost
Incinerator Size
Burner Size
Estimate Emissions for:
Organics (Table 19)
Metals (Table 20)
HCl (Table 19)
HF (Table 19)
Particulate Matter (Table 4)
Fugitives (Worksheet D)
SO2 (Table 19)
Do Emissions Exceed Standards or Desired Levels?
Yes
Estimate Emissions Reduction with Applicable Control Equipment
No
Return to Figure 9, Step 7

Figure 10. Flowchart for incineration air emissions estimation.

TABLE 19 EMISSION FACTOR (EF) EQUATIONS FOR INCINERATION SYSTEMS[a]

Emission Type	Emission Equation - Metric	Emission Equation - English
Organic Compounds ($\geq$1000 ppm in waste feed)	$((1-(DRE/100))/1000)(C_1)(m_w)$	$((1-(DRE/100))/1000)(C_1)(m_w)$
Particulate Matter (liquid incinerators)	$(m_w\ (Ash/1000))(1-CE/100)$	$(m_w(Ash/1000)(1-CE/100)$
Metals	$C_1(m_w)(\%\ MF/100)$	$C_1(m_w)(\%\ MF/100)$
HCl	$C_{Cl}(1.028\ kg\ HCl/kg\ Cl)m_w$	$C_{Cl}(1.028\ lb\ HCl/lb\ Cl)m_w$
SO_2	$C_S\ (2\ kg\ SO_2/kg\ S)m_w$	$C_S(2\ lb\ SO_2/lb\ S)m_w$
HF	$C_F\ (1.053\ kg\ HF/kg\ F)m_w$	$C_F(1.053\ lb\ HF/lb\ F)m_w$

[a] Equation provide mass of emission (kg/hr or lb/hr) per mass of waste incinerated (in kg/hr or lb/hr). Equations are described in detail in text. Symbols are defined and units given in the front matter of the document.

As a first step towards estimating the appropriate incinerator size, the heating values of the waste (and auxiliary fuel when needed) need to be calculated. Worksheet 4-11 in Reference 46 provides a method for calculating the thermal load on the incinerator and whether auxiliary fuel is needed.

Liquid Incinerators--

For liquid incinerators, the following procedure is used to estimate an incinerator size suitable for achieving a minimum of 99.99 percent DRE (thereby allowing confirmation of the adequacy of an existing unit or specification of a new one):

1. Use Worksheet 4-2 in Reference 46 to calculate the total volumetric flow (Q) of combustion gases.

2. Calculate incinerator volume from:

$$V = RT * [(Q/(60 * P)) * ((T + 273)/298)] \qquad \text{(Eq. 1)}$$

where: V = volume (m^3);
RT = retention time (seconds);
Q = combustion gas volumetric flow rate (std. m^3/min);
P = combustion gas static pressure (atm); and
T = incinerating operating temperature (°C).

3. Determine the desired length-to-diameter ratio for the unit (typically, this is 2:1 or greater).

4. Calculate incinerator inside diameter and length from:

$$id = (2 * Q * (RT)/60\pi)^{1/3} \qquad \text{(Eq. 2)}$$

and

$$\text{Length} = 2 * id$$

where: id = incinerator inside diameter (meters); and
Length = combustion chamber length (meters).

To estimate the uncontrolled emissions of organic compounds from this unit, use the following procedure:

5. The emission rate will then be:

$$ER_i = ((1-(DRE/100))/1000)(C_i)(m_w) \qquad \text{(Eq. 3)}$$

where: ER_i = emission rate for pollutant i (kg/hr);
DRE = appropriate DRE value from Table 5;
m_w = mass flow rate for waste feed (kg/hr); and
C_i = waste feed concentration for pollutant i (g/kg).

Rotary Kiln Incinerators--

For rotary kiln incinerators, the following procedure is used to estimate an incinerator size suitable for achieving a minimum of 99.99 percent DRE:

1. Use Worksheet 4-4 in Reference 46 to calculate the total volumetric flow (q) of combustion gases in both the rotary kiln and the afterburner.

2. Calculate combustion chamber and afterburner volumes using Equation 1 for liquid incinerators.

3. Determine the length/id ratio for both the kiln and the afterburner. Then for each, calculate its dimensions using the equations in part four above.

4. Finally, emissions can be estimated using Equation 3.

Multiple Hearth Incinerators--

No unit sizing worksheets have been published, but the steps should be analogous to those for liquid and rotary kiln incinerators.

Fluidized Bed Incinerators--

No unit sizing worksheets have been published, but the steps should be analogous to those for liquid and rotary kiln incinerators.

3.3.2 Particulate Matter

Emissions of particulate matter are dependent upon waste and fuel compositions, incinerator type and operation, and the effectiveness of any air pollution control devices. Consequently for most incinerator types, no correlating equations exist for estimating particulate emissions. The one exception is liquid incinerators because of their unique operating characteristics. RCRA performance standards for hazardous waste incinerators limit particulate emissions to a maximum of 180 mg/standard m^3 (0.08 grains/scf). These standards will generally be considered applicable or relevant and appropriate requirements for the incineration of waste from NPL sites as well. For all incinerator types, typical particulate matter emissions fall in the following ranges (9):

- Uncontrolled particulate emissions: 0.5 to 23 g/m^3 (0.2 to 10 grains/dscf);
- Controlled particulate emissions: 34 to 110 mg/m^3 (0.015 to 0.05 grains/dscf).

These ranges indicate that systems with particulate emission control devices tend to meet the standard while those without do not.

As a default value for assuming uncontrolled particulate emissions, the average of the above-mentioned value may be used: 11,750 mg/m^3 (5.1 grains/scf). Similarly, the average value may be used for controlled emissions: 72 mg/m^3 (0.033 grains/scf).

Liquid Incinerators--

Because liquid incinerators do not usually generate combustion chamber bottom ash, it can be assumed that all particulate matter introduced to the incinerator, as well as any generated in the unit, will exit in the exhaust gases according to the equation (59):

$$ER_{pm} = (m_w \cdot (Ash/1000))\ ((100-CE)/100) \qquad \text{(Eq. 4)}$$

where: ER_{pm} = particulate emission rate (kg/hr);
m_w = waste feed rate (kg/hr);
Ash = ash content of waste feed (g/kg); and
CE = Particulate removal efficiency of control system (%).

Rotary Kiln, Multiple Hearth, and Fluidized Bed Incinerators--

In addition to the introduction of particulate matter to the incinerator via the waste feed stream, the mechanical operations of rotary kiln, multiple hearth, and fluidized bed incinerators are also capable of generating substantial particulate loads in the exhaust gases. No specific correlations for particulate matter emissions from these units have been published.

3.3.3 Metals

Metals are not destroyed by the incineration process; therefore, they leave the system via either the bottom ash, the solid or liquid control device residues, or the stack gas. Depending on its volatility, a metal may be present in the stack gas in either particulate or gaseous form. Figure 11 presents vapor pressure curves for various hazardous metals. There are currently no correlations available for determining the partitioning of metal emissions in incineration systems; however, a simplified and highly conservative approach to estimating air emissions of hazardous metals is to assume that all of the metals present in the feed are emitted in the stack gas. In reality, however, a majority of the medium and lower volatility metals would probably be trapped in the combustion chamber ash or control devices. Actual data from incinerator tests may also be used to estimate

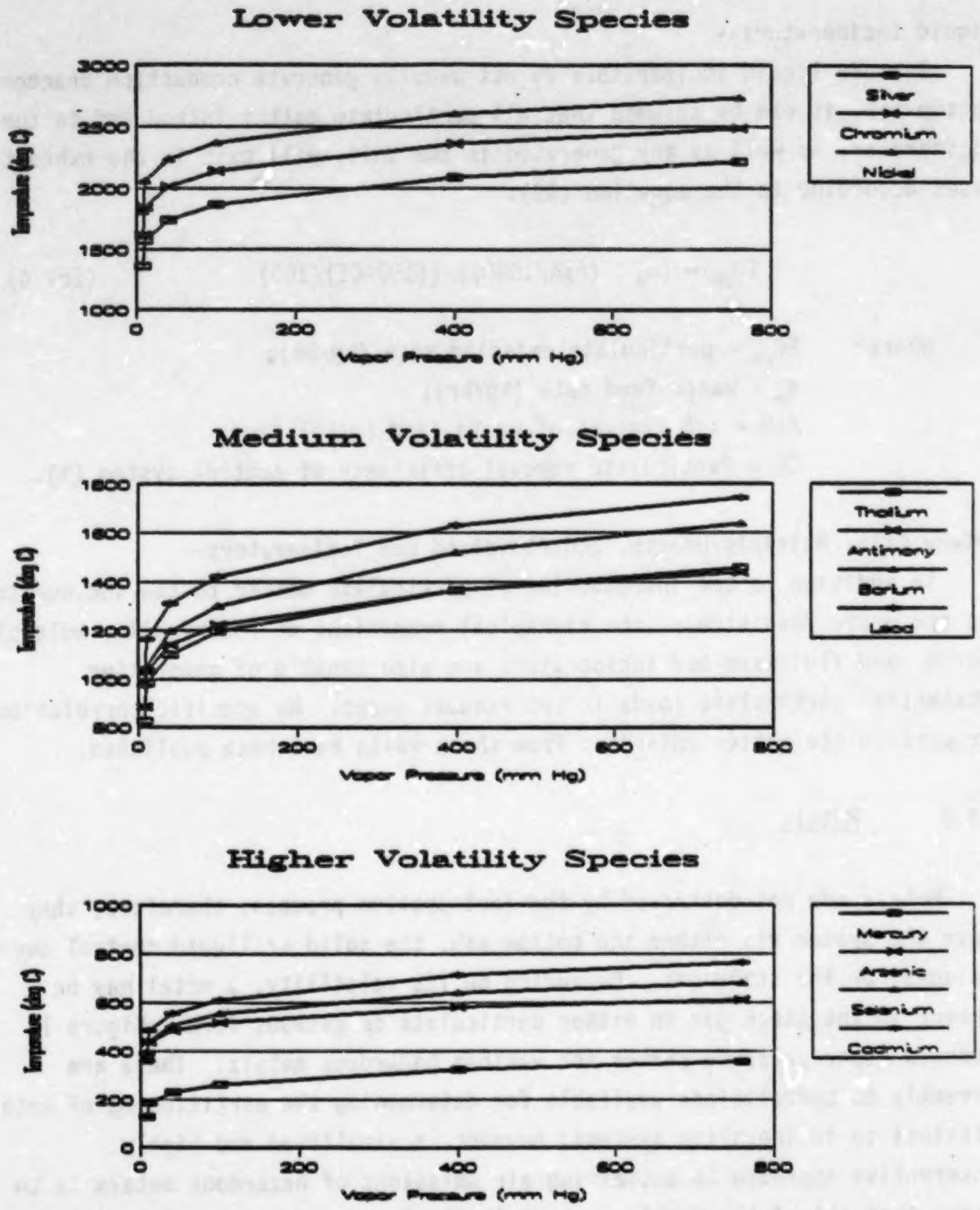


Figure 11. Vapor pressures of metals.

metals emissions. Table 20 provides typical controlled and uncontrolled emission ranges for five incinerators expressed as: (1) a function of total particulate emissions, (2) actual metal emissions, and (3) a percentage of metal fed. If the waste feed rate and the concentration of a given metal in the waste feed are known, the uncontrolled or controlled emission rates for that metal can be estimated from:

$$ER_i = (C_i)(m_w)(\%\ MF/100) \qquad \text{(Eq. 5)}$$

where: C_i = concentration of metal i in the feed (g/kg);
m_w = mass flow rate of waste (kg/hr); and
% MF = metal emitted expressed as a percentage of metal fed (from Table 20).

3.3.4 Acid Gases

The production of acid gases, including HCl, SO_2, and HF, is determined by the respective chlorine (Cl), sulfur (S), and fluorine (F) contents in the waste and fuel feed streams. A conservative approach to calculating the air emissions of these acid gases is to assume complete conversion of Cl, S, and F into their respective acid gas products. The following uncontrolled emission estimation calculations are based upon this assumption. These equations follow the form:

$$ER_i = (C_j/1000)(R_{i/j})m_w \qquad \text{(Eq. 6)}$$

where: ER_i = emission rate for acid gas i (kg/hr);
C_j = concentration of element (Cl, S, or F) in waste (g/kg);
$R_{i/j}$ = stoichiometric ratio of acid gas to element (kg/kg); and
m_w = mass flow rate of waste (kg/hr).

Table 4 presents the typical range for uncontrolled stack gas emissions of acid gases.

TABLE 20. RANGES OF PARTICULATE METALS EMISSIONS FOR FIVE HAZARDOUS WASTE INCINERATOR TESTS

	Uncontrolled Emissions			Controlled Emissions		
Metals	ug Metal per g Particulate	g Metal per Minute	% of Metal Fed	ug Metal per g Particulate	g Metal per Minute	% of Metal Fed
Antimony	300	0.7	19	<1200-15,200	<0.012-1.2	0.53-9.1
Arsenic	ND[a]	ND[a]	-[b]	ND[a]	ND[a]	-[b]
Barium	250	0.12	6.3	41-3,090	0.0032-0.12	0.038-13
Beryllium	ND[a]	ND[a]	-[b]	0.32-6	0-0.00013	0-2.2
Cadmium	140	0.069	-[b]	140-4,300	0.0033-0.087	0.94-50
Chromium	950-47,500	0.19-0.47	34-56	0-2,770	0-0.21	0-2.0
Lead	3,100	1.5	71	5,300-96,100	0.089-7.3	0.2-51
Mercury	ND[a]	ND[a]	-[b]	0-56	ND[a]	-[b]
Nickel	650-49,000	0.2-0.32	52-100	0-5,170	0.015-0.057	0.05-0.42
Selenium	9,200	4.5	87	<500-61,600	0.14-0.29	0.23
Silver	620	0.0025	-[b]	7.6-1,880	0-0.0064	-[b]
Thallium	ND[a]	ND[a]	-[b]	120-150	0.011-0.012	-[b]

[a] ND = not detected in all runs.

[b] All runs had either feed or emissions below detection limit.

Source: Reference 7.

Equations for predicting uncontrolled emissions of acid gases are shown in Table 19. Controlled emission rates for any acid gas species can be estimated by using typical emission reduction values for various types of emission control equipment and multiplying by the emission rate calculated above:

$$ER_i \text{ (controlled)} = ER_i \text{ (uncontrolled)} (1\text{-}CE/100) \quad \text{(Eq. 7)}$$

where: ER_i = emission rate for acid gas i (kg/hr); and
CE = control efficiency (% removal) from Table 6.

Of the acid gases, only HCl is currently regulated under RCRA. The performance standards for hazardous waste incinerators limit HCl emissions to a maximum of 1.8 kg/hr. If emissions from the incinerator exhaust exceed this level, then RCRA requires 99% removal via control devices.

3.3.5 NO_x

No information on NO_x emissions from incineration is currently available. In general, incinerators are not considered to be significant sources of NO_x. The form of nitrogen compound and its production rate can be controlled by controlling the incineration temperature and air-to-waste ratio.

3.3.6 Fugitive Emissions

Fugitive emissions are any uncontrolled gas or particulate matter emissions from any operation or equipment other than the exhaust stack. Sources for these emissions include leaking valve and pump fittings, flanges, storage tanks, and sampling and instrument connections. References 10 and 11 provide a series of detailed equations for estimating the fugitive emissions from each of these sources.

Fugitive emissions from materials handling may be significant, both for the waste feed into the incinerator and the ash out of it. These emissions can be estimated using the procedure given in Section 3.6 for soils handling.

3.4 AIR STRIPPING OF GROUND WATER

Estimation of emissions from air stripping of ground water is relatively simple. Air stripping towers can achieve nearly complete removal of volatile organics from ground water, so emissions estimates can be based on the slightly conservative assumption of 100% removal efficiency. The rate of uncontrolled atmospheric emissions simply equals the rate of contaminant being treated, which in turn equals the contaminant concentration in ground water multiplied by the flow rate of the ground water being stripped. The estimation of emissions becomes only slightly more complicated when adjustments are made for emissions reductions resulting from the use of control devices and for removal efficiencies that are less than 100%. With these terms added, the equation for estimating emissions becomes:

$$ER_i = (C_{i,in})(Q_{in})(10^{-6})(1-(CE/100))(RE/100) \qquad \text{(Eq. 8)}$$

where: ER_i = emission rate for species i (g/min);
$C_{i,in}$ = concentration of species i in influent ground water (ug/L);
Q_{in} = flow rate (L/min);
RE = removal efficiency (%); and
CE = control efficiency (%).

As discussed in Section 2, removal efficiencies for air stripping of ground water will vary with numerous factors such as operating temperature, tower height, and air-to-water ratio. The best emission estimates will consider design parameters. Nevertheless, for volatile organic contaminants, a reasonable default is to assume a removal efficiency of 99.5%, so Equation 8 reduces to:

$$ER_i = (C_i)(Q_{in})(9.95\times10^{-7})(1-(CE/100)) \qquad \text{(Eq. 9)}$$

A typical flow rate to assume for preliminary emissions estimates is 1000 liters per minute. If multiple air stripping towers are used, then the emissions from each must be summed to determine the total emissions.

For semi-volatile organic compounds or inorganic contaminants, the removal efficiency from air stripping may be assumed to be 0%. If site-specific data are available, emissions can be calculated using Equation 10.

$$ER_i = \frac{(C_{i,in})(Q_{in}) - (C_{i,out})(Q_{out})}{10^6} \qquad \text{(Eq. 10)}$$

where: $C_{i,out}$ = concentration of species i in effluent (ug/L); and
Q_{out} = effluent flow rate (L/min).

Note that the flow rates of the influent and effluent streams will differ due to evaporative losses in the air stripping tower.

Control efficiency will vary with the inlet gas VO concentration and the type of VOs present. Inlet streams of about 200-10,000 ppm VO can be treated, with exhaust gas concentrations of 50-100 ppm VO obtainable. The following values can be assumed:

VO Type	Inlet VO Concentration (ppmv)	Control Efficiency
Molecular Weight = <45	-	0%
Molecular Weight = 45-130	200-500	50%
	1000-2000	95%
	5000-10000	99%
Molecular Weight = >130	-	100% (permanently bound to carbon)

3.5 IN-SITU VENTING

Emissions from in-situ venting are extremely site-specific. No predictive equations exist. A theoretical framework for venting emissions is presented below; however, not all variables shown are known for all or most sites. Subsequently, equations for estimating recovery rates are given.

The volumetric flow rate of VO-laden air vented from subsurface soils is described by Darcy's law, an empirical law which states that the velocity (volumetric flow through a cross-sectional area) is proportional to the hydraulic gradient (the sum of pressure and gravity gradients). Darcy's law is expressed through the following equation:

$$v = Q/A = -(k_a/n_a)\Delta(P_a + d_a gh) \qquad \text{(Eq. 11)}$$

where: v = discharge velocity (m/sec);
Q = volumetric flow rate through well (m^3/sec);
A = cross-sectional area of well (m^2);
k_a = air permeability in soil (m^2);
n_a = viscosity of air ($N \cdot sec/m^2$);
P_a = pressure of air (N/m^2);
d_a = density of air (kg/m^3);
g = acceleration due to gravity (m/sec^2);
h = elevation (m); and
Δ = gradient (m^{-1}).

During vacuum venting, the induced pressure gradient overwhelms the gravity gradient, and Darcy's law reduces to:

$$v = Q/A = -(k_a/n_a)(P_2-P_1)/l_{12} \qquad \text{(Eq. 12)}$$

where: P_2 = air pressure at point 2 (low pressure);
P_1 = air pressure at point 1 (high pressure); and
l_{12} = distance from point 1 to point 2 as shown in Figure 12.

However, application of this equation to estimating the mass flow of organics to the surface through the well is extremely complex. Air permeability may be estimated roughly from site moisture and water permeability data, although the margin of error may not be estimable without air permeability data. Site-specific data from the Soil Conservation Service on moisture content and water permeability are usually valid for depths of

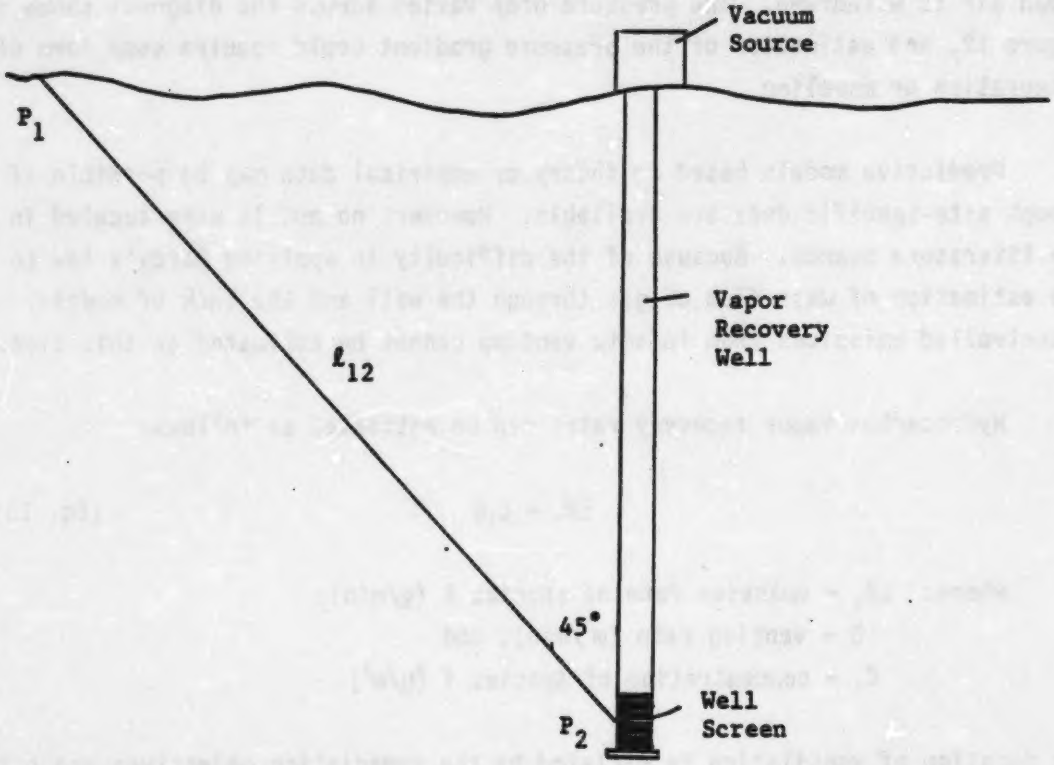

Vacuum
Source
P_1
ℓ_{12}
Vapor
Recovery
Well
45°
Well
Screen
P_2

Figure 12. Schematic of vapor recovery well and associated pressure gradient.

only five or six feet; vapor recovery wells usually draw from much greater depths. In addition, the actual moisture content of the soil is highly variable, probably varying spatially and temporally at some sites. No empirical means of estimating the air permeability from moisture or water permeability data were found in the literature (47,48,49).

The pressure differential term is also difficult to estimate. Because of the vacuum suction, air is constantly drawn into the soil while the VO-laden air is withdrawn. The pressure drop varies across the diagonal shown in Figure 12, and estimation of the pressure gradient would require some form of integration or modeling.

Predictive models based on theory or empirical data may be possible if enough site-specific data are available. However, no models were located in the literature search. Because of the difficulty in applying Darcy's law to the estimation of mass flow of gas through the well and the lack of models, uncontrolled emissions from in-situ venting cannot be estimated at this time.

Hydrocarbon vapor recovery rates can be estimated as follows:

$$ER_i = C_i Q \qquad \text{(Eq. 13)}$$

where: ER_i = emission rate of species i (g/min);
Q = venting rate (m^3/min); and
C_i = concentration of species i (g/m^3).

The duration of ventilation is dictated by the remediation objectives and site characteristics. The vented gas concentration typically decreases exponentially over time. If the total mass of volatile species present is known, then the duration of operation can be estimated from the vapor recovery rate. If, as is usual, the amount of volatiles present is unknown, then operation of the subsurface venting system for one year is a reasonable assumption.

The liquid product recovery rate can be computed as:

$$LP_r = (ER_i)/(1000\ mL/L)d_L \qquad \text{(Eq. 14)}$$

where: LP_r = liquid product recovery rate (L/min); and
d_L = density of liquid (g/mL).

If emissions control is desired, the selection of a control method should consider the VO concentration in the soil gas. If the VO concentration is greater than 10,000 ppm, it is recommended that the vent stream be pretreated by condensing the VOs, as discussed in Section 2.1.3. When the VO concentration is between 200 and 10,000 ppm, carbon adsorption should be adequate to control organic emissions.

Efficiency of control varies depending on the VO concentration in the gas to be treated, but carbon adsorption can usually reduce the VOs in the exit gas to concentrations of 50 to 100 ppm. Carbon adsorption technology is discussed in greater detail in Section 2.2 of this report under Air Stripping of Groundwater.

3.6 SOILS HANDLING

3.6.1 Presentation of Equations and Steps in the Process

The steps necessary to calculate emission factors for soil handling remedial activities are shown in the flowchart in Figure 13. The overall process of estimating emissions requires determination of:

- The activities required for soils handling;
- The potential for emissions of volatile organics and metals (the emission of particulate matter is assumed by definition of soils handling);
- The particulate size (diameter) of interest;

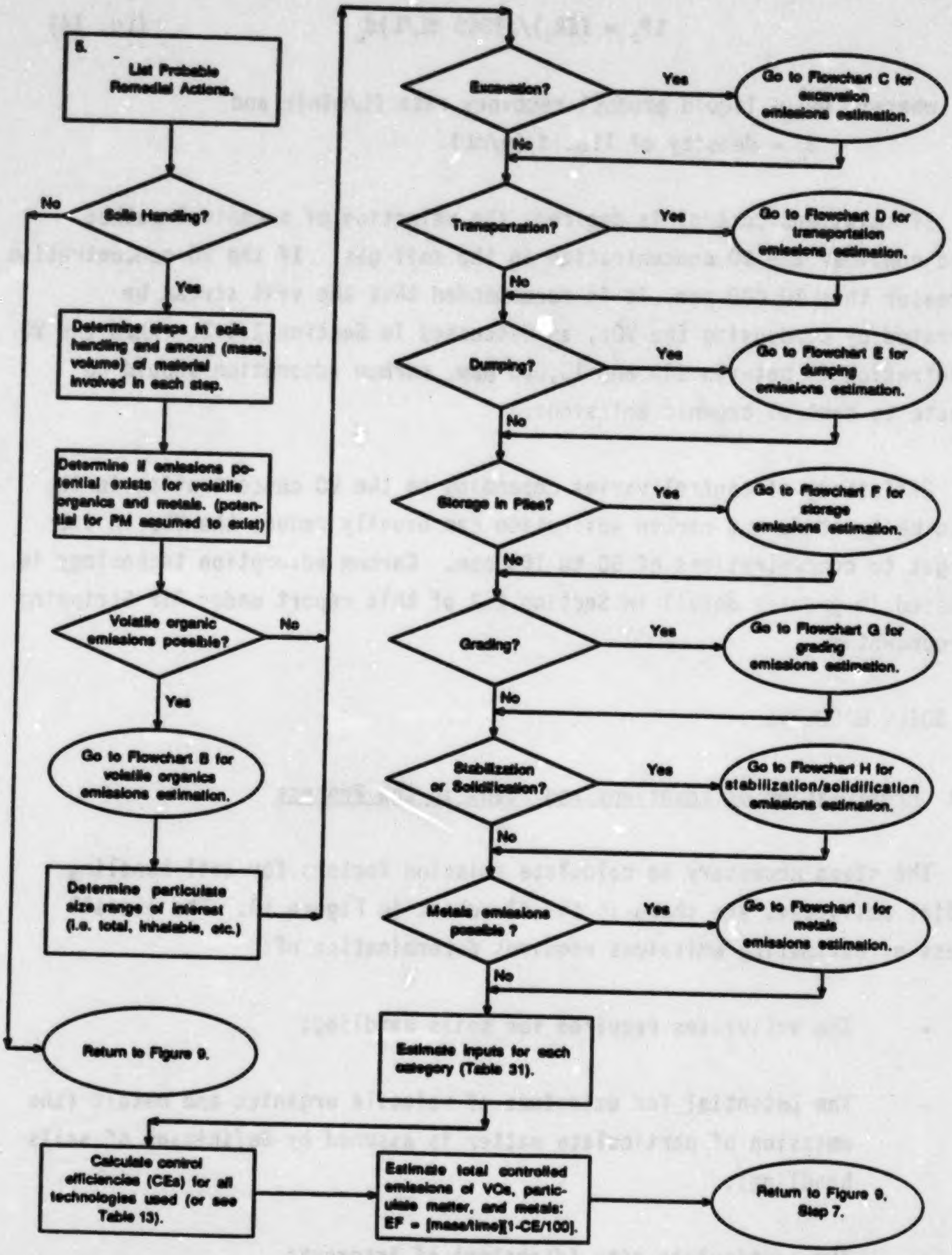

8.
List Probable Remedial Actions.
Soils Handling?
No
Yes
Determine steps in soils handling and amount (mass, volume) of material involved in each step.
Determine if emissions potential exists for volatile organics and metals. (potential for PM assumed to exist)
Volatile organic emissions possible?
No
Yes
Go to Flowchart B for volatile organics emissions estimation.
Determine particulate size range of interest (i.e. total, inhalable, etc.)
Return to Figure 9.
Excavation?
Yes
Go to Flowchart C for excavation emissions estimation.
No
Transportation?
Yes
Go to Flowchart D for transportation emissions estimation.
No
Dumping?
Yes
Go to Flowchart E for dumping emissions estimation.
No
Storage in Piles?
Yes
Go to Flowchart F for storage emissions estimation.
Grading?
Yes
Go to Flowchart G for grading emissions estimation.
No
Stabilization or Solidification?
Yes
Go to Flowchart H for stabilization/solidification emissions estimation.
No
Metals emissions possible ?
Yes
Go to Flowchart I for metals emissions estimation.
No
Estimate inputs for each category (Table 31).
Calculate control efficiencies (CEs) for all technologies used (or see Table 13).
Estimate total controlled emissions of VOs, particulate matter, and metals: EF = [mass/time][1-CE/100].
Return to Figure 9, Step 7.

Figure 13. Flowchart A: Soils handling emissions estimating methodology.

- The emission factors for organic, particulate, and metal contaminants (if applicable) for each soils handling activity;
- Which (if any) emission controls are necessary; and
- The emission rate (mass per time), which is converted from the emission factor (mass per unit operation).

Soils Handling Activities--

The development of emission factors is dependent on knowing which soils handling activities will be necessary at the site and the mass or volume of soil handled in each activity. The steps have been divided into six categories which were discussed in greater detail in Section 2.1.2:

- Excavation of soil from the site surface;
- Transportation of the soil to storage or other sites;
- Dumping of the soil into trucks, piles, etc.;
- Storage of the soil in piles (wind erosion); and
- Grading the treated or replacement soil.

Emissions Potential--

Data from site characterization studies such as those performed under the RI should identify the organic and metal content of the soil. If the soil contains organic compounds which could volatilize if the soil is disturbed, then the potential for VO emissions exists, and potential emissions should be estimated. If metal analyses of the soil have been performed, and heavy metals are present in the soil covering, the potential exists for emissions of metals adsorbed onto particulate surfaces. If no soil data are available, but metals are present in the underlying wastes in forms that can diffuse into the soil, the potential for metal emissions from the site may still exist. Small inhalable particulates can carry adsorbed metals into the lungs and hence the bloodstream.

It should be noted that particulate matter is expected to be emitted from soils handling operations; therefore, the potential for particulate emissions is assumed to exist.

Particle Size of Interest--

It is important to determine the particulate size range of interest, since emission factors/equations are available for several ranges. Most of the equations determine TSP (total suspended particulate) emissions, which are particles with an aerodynamic physical diameter of about 30 microns or less. The primary equations are summarized in Table 21 with parameters defined in Table 22. Equations for the dumping and transportation categories include particle size multipliers (k) which allow the estimation of 15 micron and smaller particulate emissions. Particle size multipliers are given in Table 23. Separate equations are used for the excavation and grading categories to determine smaller particulate emissions; these equations are shown in Table 24. Table 25 has typical size ranges of emissions as percent of TSP for use in estimating size ranges for storage emissions and comparing these to other categories.

The user may extrapolate results to estimate emissions of particulate matter of less than 10 microns.

Volatile Organic Emission Factors--

The search for existing estimation procedures turned up little in the way of theoretically sound approaches for estimating VO emissions from dynamic processes such as soils handling. However, many predictive models exist for estimating VO emissions from static sources and EPA is currently working to modify these models to address dynamic processes. Ultimately, it is hope that predictive models will be developed that have the general form:

$$ER_i = (C_i)(V)(A)(X\text{-stripping rate})(K_{SF})(K_{WF}) \qquad \text{(Eq. 15)}$$

where: ER_i = emission rate for species i or total VOs (g/min-m^2);
C_i = concentration of species i in soil (g/m^3);
V = volume of soil handled (m^3);

TABLE 21. EMISSION FACTOR (EF) EQUATIONS FOR SOILS HANDLING (TOTAL SUSPENDED PARTICULATE)

Category	Emission Equations - Metric	Metric EF Units	Emission Equations - English	English EF Units	Rating[a]	Reference
Excavation						
Bulldozer	$2.6(s)^{1.2}(M)^{-1.3}$	kg/hr	$5.7(s)^{1.2}(M)^{-1.3}$	lb/hr	C	31
Dragline	$0.0046(d)^{1.1}(M)^{-0.3}$	kg/m^3	$0.0021(d)^{1.1}(M)^{-0.3}$	lb/yd^3	C	31
Scraper	$9.6\times10^{-6}(s)^{1.3}(W)^{2.4}$	kg/VKT	$2.7\times10^{-5}(s)^{1.3}(W)^{2.4}$	lb/VMT	B	31
Transport						
Unpaved Roads	$k(1.7)(\frac{s}{12})(\frac{S}{48})(\frac{W}{2.7})^{0.7}(\frac{w}{4})^{0.5}(\frac{365-p}{365})$	kg/VKT	$k(5.9)(\frac{s}{12})(\frac{S}{30})(\frac{W}{3})^{0.7}(\frac{w}{4})^{0.5}(\frac{365-p}{365})$	lb/VMT	A	31
Industrial Paved Roads	$0.022\ I\ (\frac{4}{n})(\frac{s}{10})(\frac{L}{280})(\frac{W}{2.7})^{0.7}$	kg/VKT	$0.077\ I\ (\frac{4}{n})(\frac{s}{10})(\frac{L}{1000})(\frac{W}{3})^{0.7}$	lb/VMT	B	31
Dry Ind. Roads. Med. & Heavy Vehicles	$k(\frac{sL}{12})^{0.3}$	kg/VKT	$3.5k(\frac{sL}{0.35})^{0.3}$	lb/VMT	A	31[b]
Uncovered Truck Bed	$0.0018u$	kg/m^2·hr	$0.00015u$	lb/yd^2·hr	NA	-
Dumping	$k(0.0016)(\frac{U}{2.2})^{1.3}(\frac{M}{2})^{-1.4}$	kg/Mg	$k(0.0032)(\frac{U}{5})^{1.3}(\frac{M}{2})^{-1.4}$	lb/ton	A	31[b]
Storage (Active Piles)						
Annual Estimate	$1.9(\frac{s}{1.5})(\frac{365-p}{235})(\frac{f}{15})$	kg/day/hectare	$1.7(\frac{s}{1.5})(\frac{365-p}{235})(\frac{f}{15})$	lb/day/acre of surface	D	31
Short-Term (24-hour)	$1.8u$	kg/hectare/hour	$0.72u$	lb/acre/hour	NA	33
Grading	$0.0034(S)^{2.5}$	kg/VKT	$0.040(S)^{2.5}$	lb/VMT	C	31

[a] If parameters for transportation and dumping fall outside the range shown in Table 3-14, rating should be dropped one letter (A = highest confidence) except for Industrial Paved roads, which should be dropped two letters.

[b] From 1987 Draft AP-42.

NA = not available.
- = not applicable/dimensionless

NOTE: See Table 22 for units and explanation of variables.

TABLE 22. DEFINITIONS OF PARAMETERS AND UNITS FOR SOILS HANDLING EMISSION FACTORS

Parameter	Definition	Unit	Category
s	Silt content of material	wt. %	E,T
M	Moisture content of material	wt. %	E,T,D
d	Drop height	m or ft	E
W	Mean vehicle weight	Mg or tons	E,T
w	Mean number of wheels	-	T
S	Mean vehicle speed	km/hr or mph	T,G
k	Particle size multipler	-	T,D
p	Number of days/yr with ≥0.254 mm (0.01 inches) of precipitation	-	T
I	Industrial augmentation factor = 1.0 traffic only on paved roads = 3.5 industrial roadway, unpaved shoulders, 20% of vehicles forced to travel temporarily with one set of wheels on shoulder = 7.0 paved industrial roadway, traffic enters from unpaved areas	-	T
n	Number of traffic lanes	-	T
L	Surface dust loading	kg/km or lb/mile	T
U	Mean wind speed	m/sec or mph	D,S
sL	Road surface silt loading	g/m^2 or oz/yd^2	T
u	Sum of wind speed and vehicle speed	m/sec or mph	T
f	Percentage of time that the unobstructed wind speed is >5.4 m/sec (12 mph) at the mean pile height	%	s
VkT	Vehicle kilometer traveled	km	T
VmT	Vehicle mile traveled	mile	T

E = excavation
T = transportation
D = dumping
S = storage
G = grading

- dimensionless

TABLE 23. TYPICAL PARTICLE SIZE MULTIPLIERS (k, dimensionless)

Size Range of Interest	Unpaved roads	Dry Industrial Roads	Dumping
≤30 um, Stokes Diameter	1.0	NS	NS
≤30 um	0.8	NS	0.74
≤15 um	0.5	0.28	0.48
≤10 um	0.36	0.22	0.35
≤5 um	0.20	NS	0.20
≤2.5 um	0.095	0.081	0.11

NS = not stated.

TABLE 24. EMISSION RATE EQUATIONS FOR INHALABLE OR SMALLER PARTICULATES: EXCAVATION AND GRADING

Emission Category	Size Range	Emission Equation - Metric	Units	Emission Equation - English	Units
Excavation					
Bulldozer	<15 um	$0.45(s)^{1.5}(M)^{-1.4}$	kg/hr	$1.0(s)^{1.5}(M)^{-1.4}$	lb/hr
	<2.5 um	$(0.105)(2.6)(s)^{1.2}(M)^{-1.3}$	kg/hr	$(0.105)(5.7)(s)^{1.2}(M)^{-1.3}$	lb/hr
Dragline	<15 um	$(0.0029)(d)^{0.7}(M)^{-0.3}$	kg/m^3	$0.0021(d)^{0.7}(M)^{-0.3}$	lb/yd^3
	<2.5 um	$(0.017)(0.0046)(d)^{1.1}(M)^{-0.3}$	kg/m^3	$(0.017)(0.0021)(d)^{1.1}(M)^{-0.3}$	lb/yd^3
Scraper	<15 um	$(2.2\text{x}10^{-6})(s)^{1.4}(W)^{2.5}$	kg/VKT	$(6.2\text{x}10^{-6})(s)^{1.4}(W)^{2.5}$	lb/VMT
	<2.5 um	$0.026(9.6\text{x}10^{-6})(s)^{1.3}(W)^{2.4}$	kg/VKT	$0.026(2.7\text{x}10^{-5})(s)^{1.3}(W)^{2.4}$	lb/VMT
Grading	<15 um	$0.0056(S)^{2.0}$	kg/VKT	$0.051(S)^{2.0}$	lb/VMT
	<2.5 um	$0.031(0.0034)(S)^{2.5}$	kg/VKT	$0.031(0.040)(S)^{2.5}$	lb/VMT

NOTE: See Table 22 for units and explanation of symbols.

TABLE 25. TYPICAL PARTICULATE SIZE DISTRIBUTIONS AS WEIGHT PERCENT OF EMISSIONS

Category	≤3 um	≤5 um	3-30 um	5-30 um	>30 um	Reference
Aggregate Storage Piles	30	-	23	-	47	28,29
Paved Road/Surface	-	50	-	40	10	29
	40	-	37	-	23	28
Unpaved Road/Surface	31	-	29	-	40	28
Gravel	-	23	-	39	38	29
Dirt	-	8	-	24	68	29
Mining Emissions						
Overburden Removal	5	-	7	-	88	29
Truck Loading	4.5	-	8.5	-	87	29
Exposed Areas[a]	5	-	8	-	87	29
Other[b]	5.5	-	9.5	-	85	29

[a] Includes waste and reclamation areas prior to revegetation.

[b] Other mining activities include haul roads, truck dumping, and storage.

- = not applicable/not available.

A = surface area of working area (m^2);
X = stripping rate for remedial option X (% of species i/min);
K_{SF} = lumped soil-related factors (unitless); and
K_{WF} = lumped waste-related factors (unitless).

This approach, once fully developed and validated, would allow estimation of organic emissions based primarily on knowledge of the average concentration of VOs or individual compounds in a given area to be remediated.

Limited field data is available to support a second approach for estimating VO emissions based on measuring a baseline emission rate and multiplying this value by an "agitation factor" to account for the increase in emission rate due to disturbance of the soil. This estimation procedure is based on empirical data and provides only a very rough estimate of emissions. The estimation procedure for any given waste cell is illustrated to Figure 14. It should be kept in mind that the baseline emission estimate refers to emissions from the exposed waste or contaminated soil. Any overburden will greatly diminish emissions, as shown in Table 26, and make the estimation problematic.

The initial step is to identify or estimate pertinent chemical and physical properties of the waste. The key parameters are the type of VOs present, their concentration, and the matrix surrounding the waste. An additional parameter is the depth (and porosity) of any overburden. However, during soils handling the waste is typically in direct contact with the atmosphere.

Next, a baseline VO emission rate should be estimated. Detailed guidance for this type of estimation is contained in a companion manual (2). Three procedures for estimating baseline emissions are available. These are in order of preference:

- Use the site-specific emission rate collected during RI/FS;
- Use an appropriate emission model; or
- Use a value from Table 26.

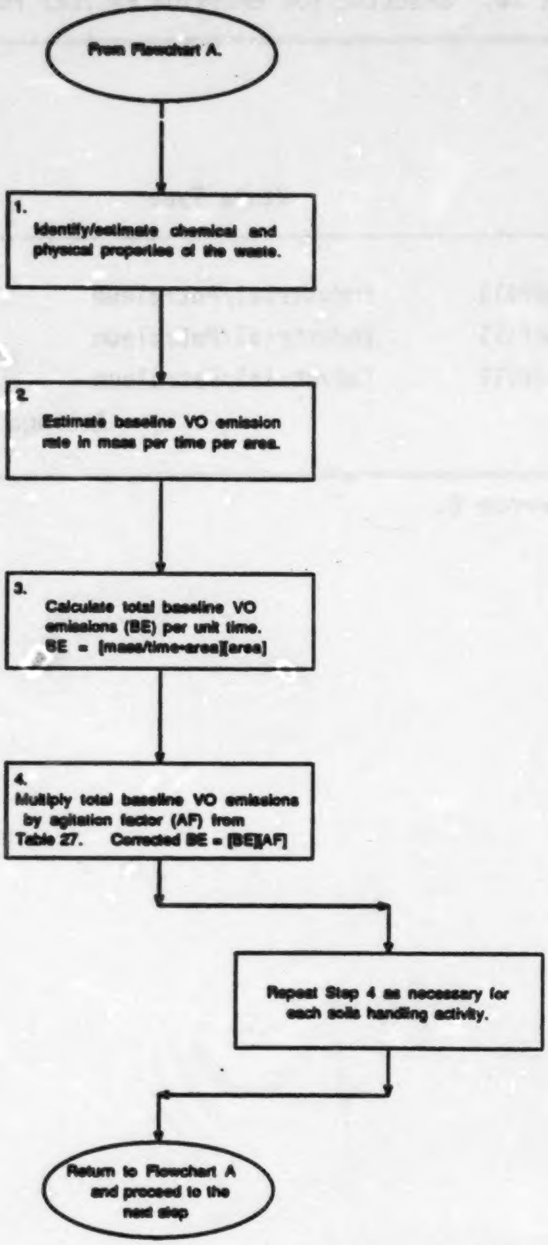

From Flowchart A.
1.
Identify/estimate chemical and physical properties of the waste.
2.
Estimate baseline VO emission rate in mass per time per area.
3.
Calculate total baseline VO emissions (BE) per unit time.
BE = [mass/time-area][area]
4.
Multiply total baseline VO emissions by agitation factor (AF) from Table 27. Corrected BE = [BE][AF]
Repeat Step 4 as necessary for each soils handling activity.
Return to Flowchart A and proceed to the next step

Figure 14. Flowchart B: Estimating volatile organic emissions.

TABLE 26. BASELINE VOC EMISSION FACTORS FOR HAZARDOUS WASTES

		Emission Rate (ug/m^2-min)	
Site	Waste Type	Covered Waste	Exposed Waste
Abandoned Landfill	Industrial/Petroleum	360	190,000
Abandoned Landfill	Industrial/Petroleum	740	26,000
Abandoned Landfill	Industrial/Petroleum	29	170,000
	Average	380	130,000

Source: Reference 2.

Because such limited data is available in Table 26, the use of the average value is the only reasonable option when selecting a value from this table. Emission models are discussed briefly in Section 5.2 of this manual.

The emission models typically provide an emission rate in mass per unit time per unit surface area. The applicable surface area should be estimated, e.g., surface area of the truck bed. The surface roughness of the soil material may double the actual soil surface area for a given size and should be taken into account. A total baseline VO emission rate is calculated by multiplying the emission rate derived from a model or other method by the estimated surface area.

Soils handling increases the emission rate over baseline emissions. This degree of enhancement (the agitation factor) is estimated in Table 27 for each soils handling step. The agitation factors are not well characterized and are further affected by the chemical and physical properties of the waste, and by the applicable meteorological conditions.

Particulate Matter (PM) Emission Factors--

The equations and procedures for estimating particulate emissions during soil handling are considerably more complicated than those for estimating emissions for volatile organics. Each soils handling activity has its own set of equations, and the steps for determining process emissions are broken into separate flowcharts for each category. These are given in Figures 15 through 19. The silt fraction of soil generally has "enriched" concentrations of metals relative to the soil as a whole due to the increased surface area to weight ratio of the silt. Figure 20 contains a flowchart for determining the enrichment of the eight RCRA metals on silt particles ($\leq$75 um diameter). These enrichment factors multiplied by the contaminant concentrations in a total soil sample will provide an estimate of the metal concentration in the emitted particulate matter.

TABLE 27. INCREASE IN EMISSIONS DUE TO SOILS HANDLING

Soils Handling Category	Agitation Factor[a]	Reference
Excavation		
Backhoe	2.5-28	50
Dragline	-	
Scraper	-	
Bulldozer	36-63	51
Transport		
Conveyor Belt	36	51
Truck	-	
Dumping[b]	42-72	51
Storage		
Short-term[c]	10	51
Long-term	1	Assumed
Stabilization	-	
Grading[d]	4 (2-9)	52
	2.5-38	53

[a] Multiply agitation factor by baseline emissions estimate (BEE) to calculate VOC emission factor.

[b] Values from crushing of ore.

[c] <4 days.

[d] Values from tilling of waste.

- = No data available

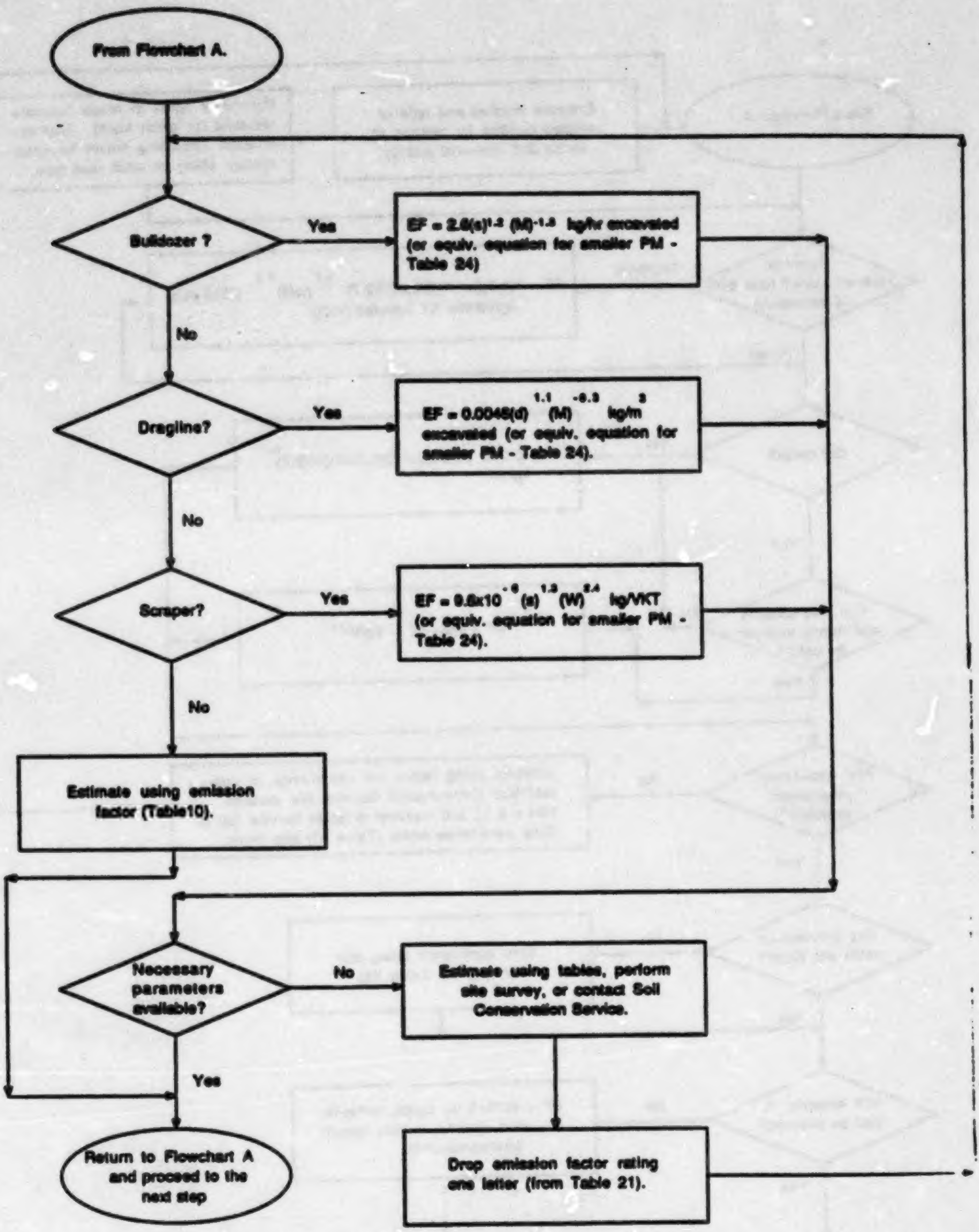

From Flowchart A.
Bulldozer ?
Yes
EF = 2.6(s)^1.2 (M)^-1.3 kg/hr excavated (or equiv. equation for smaller PM - Table 24)
No
Dragline?
Yes
EF = 0.0046(d)^1.1 (M)^-0.3 kg/m^3 excavated (or equiv. equation for smaller PM - Table 24).
No
Scraper?
Yes
EF = 9.6x10^-6 (s)^1.3 (W)^2.4 kg/VKT (or equiv. equation for smaller PM - Table 24).
No
Estimate using emission factor (Table10).
Necessary parameters available?
No
Estimate using tables, perform site survey, or contact Soil Conservation Service.
Yes
Return to Flowchart A and proceed to the next step
Drop emission factor rating one letter (from Table 21).

Figure 15. Flowchart C: Estimating excavation emissions.

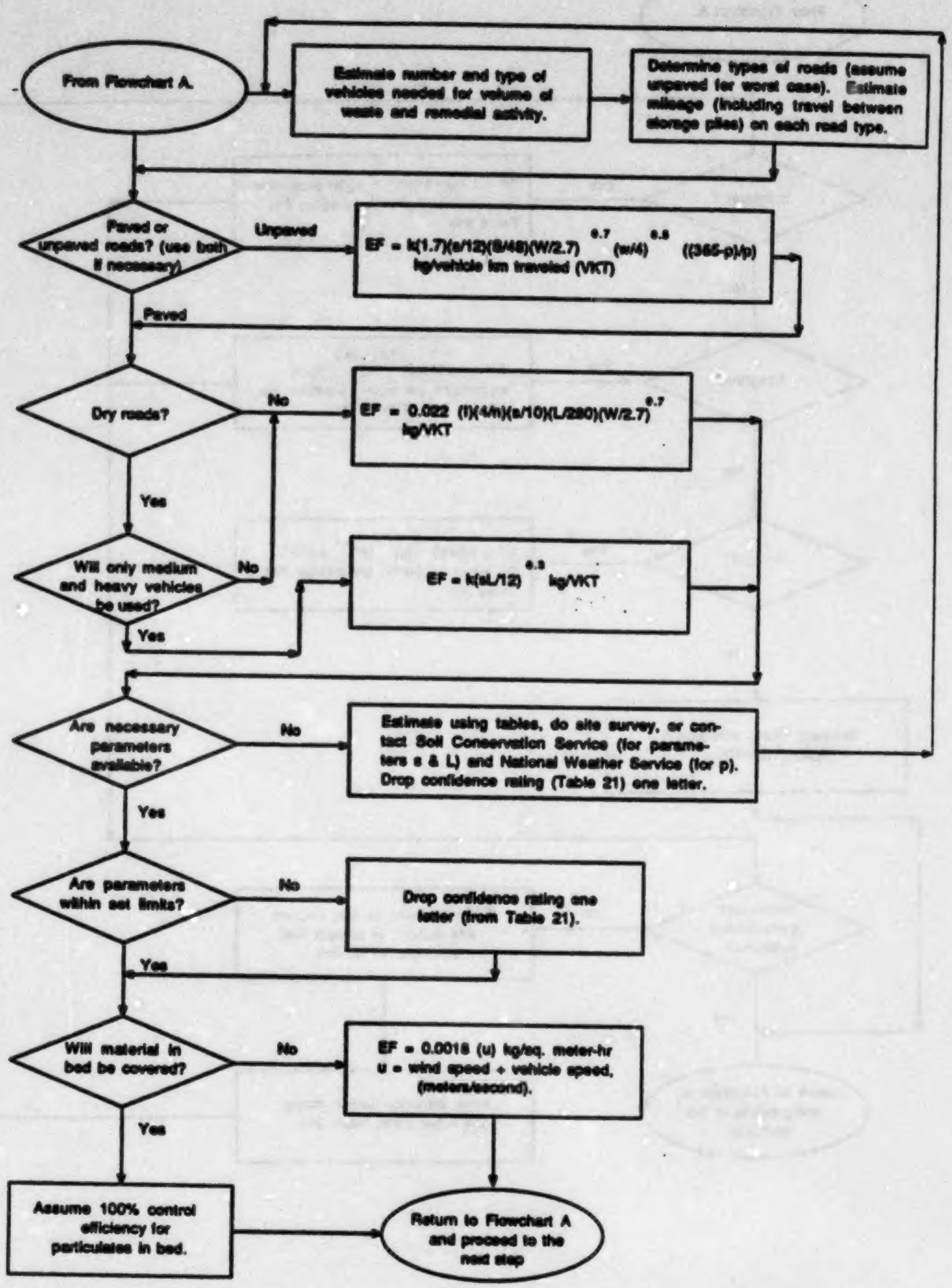

From Flowchart A.
Estimate number and type of vehicles needed for volume of waste and remedial activity.
Determine types of roads (assume unpaved for worst case). Estimate mileage (including travel between storage piles) on each road type.
Paved or unpaved roads? (use both if necessary)
Unpaved
EF = k(1.7)(s/12)(S/48)(W/2.7)^0.7 (w/4)^0.5 ((365-p)/p) kg/vehicle km traveled (VKT)
Paved
Dry roads?
No
EF = 0.022 (I)(4/n)(s/10)(L/280)(W/2.7)^0.7 kg/VKT
Yes
Will only medium and heavy vehicles be used?
No
EF = k(sL/12)^0.3 kg/VKT
Yes
Are necessary parameters available?
No
Estimate using tables, do site survey, or contact Soil Conservation Service (for parameters s & L) and National Weather Service (for p). Drop confidence rating (Table 21) one letter.
Yes
Are parameters within set limits?
No
Drop confidence rating one letter (from Table 21).
Yes
Will material in bed be covered?
No
EF = 0.0018 (u) kg/sq. meter-hr u = wind speed + vehicle speed, (meters/second).
Yes
Assume 100% control efficiency for particulates in bed.
Return to Flowchart A and proceed to the next step

Figure 16. Flowchart D: Estimating transport emissions.

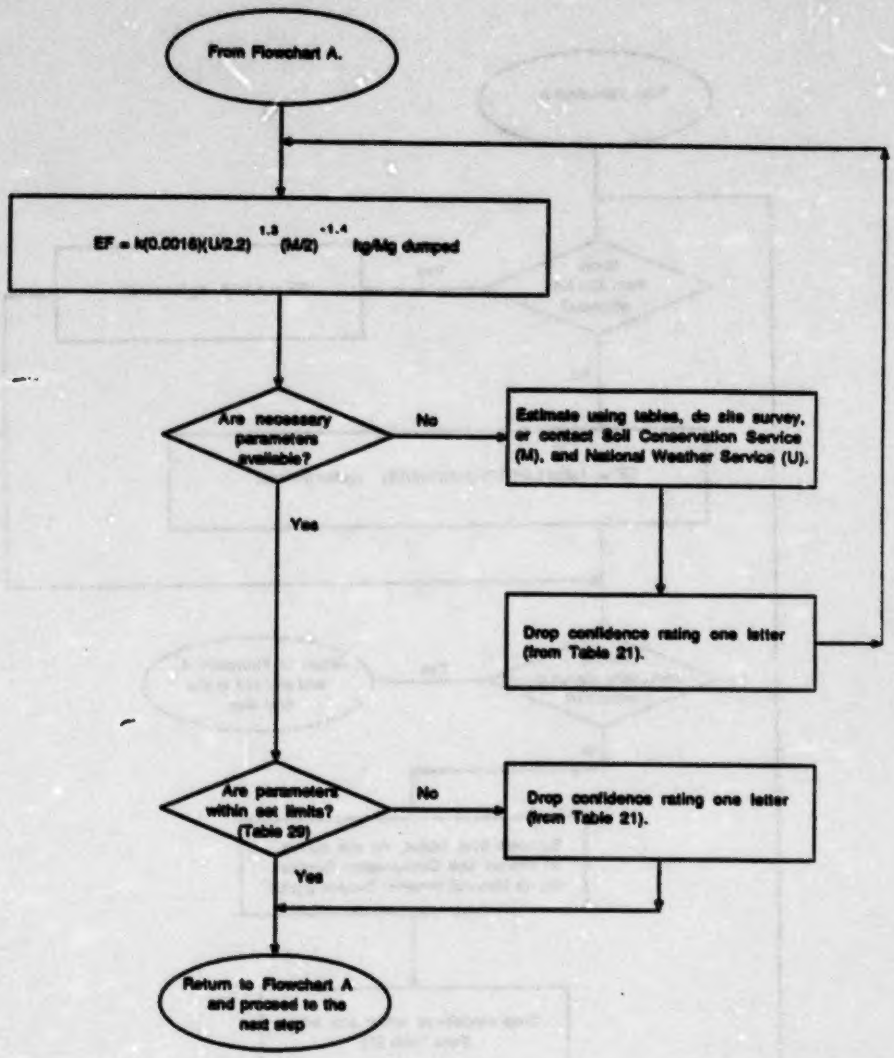

From Flowchart A.
EF = k(0.0016)(U/2.2)^1.3 (M/2)^-1.4 kg/Mg dumped
Are necessary parameters available?
No
Estimate using tables, do site survey, or contact Soil Conservation Service (M), and National Weather Service (U).
Drop confidence rating one letter (from Table 21).
Yes
Are parameters within set limits? (Table 29)
No
Drop confidence rating one letter (from Table 21).
Yes
Return to Flowchart A and proceed to the next step

Figure 17. Flowchart E: Estimating dumping emissions.

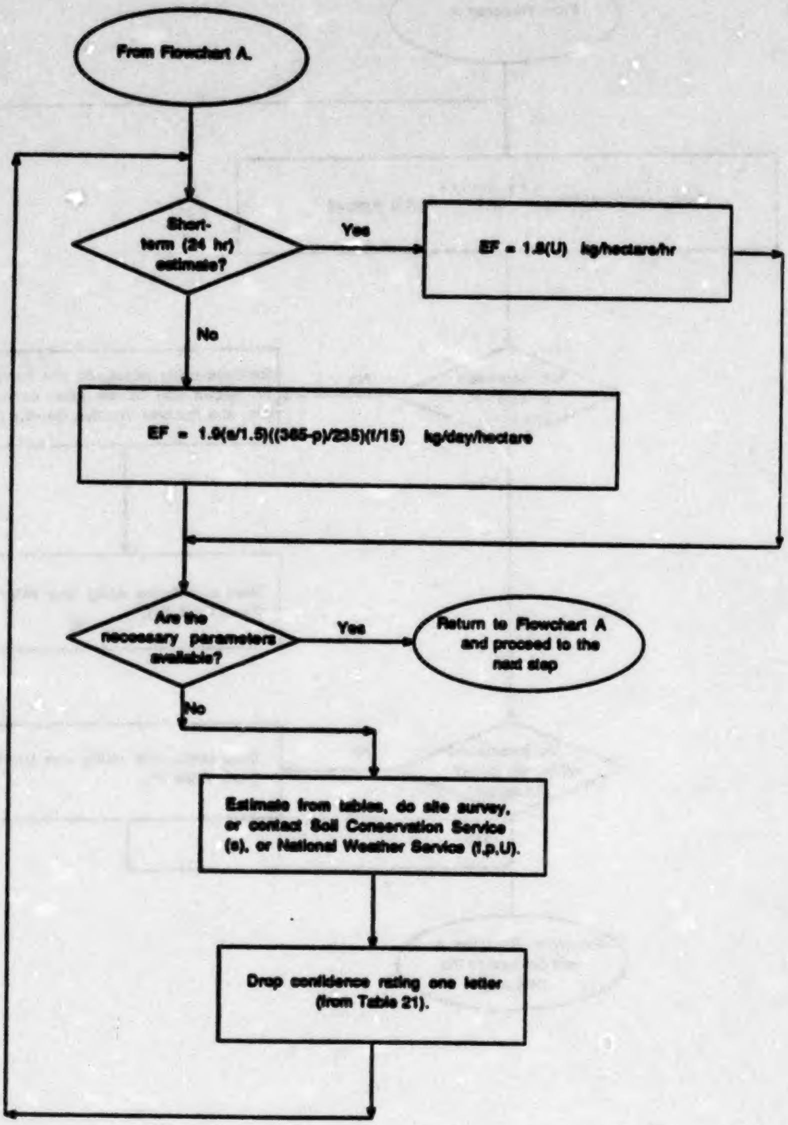

From Flowchart A.
Short-term (24 hr) estimate?
Yes
EF = 1.9(U) kg/hectare/hr
No
EF = 1.9(s/1.5)((365-p)/235)(f/15) kg/day/hectare
Are the necessary parameters available?
Yes
Return to Flowchart A and proceed to the next step
No
Estimate from tables, do site survey, or contact Soil Conservation Service (s), or National Weather Service (f,p,U).
Drop confidence rating one letter (from Table 21).

Figure 18. Flowchart F: Estimating storage emissions.

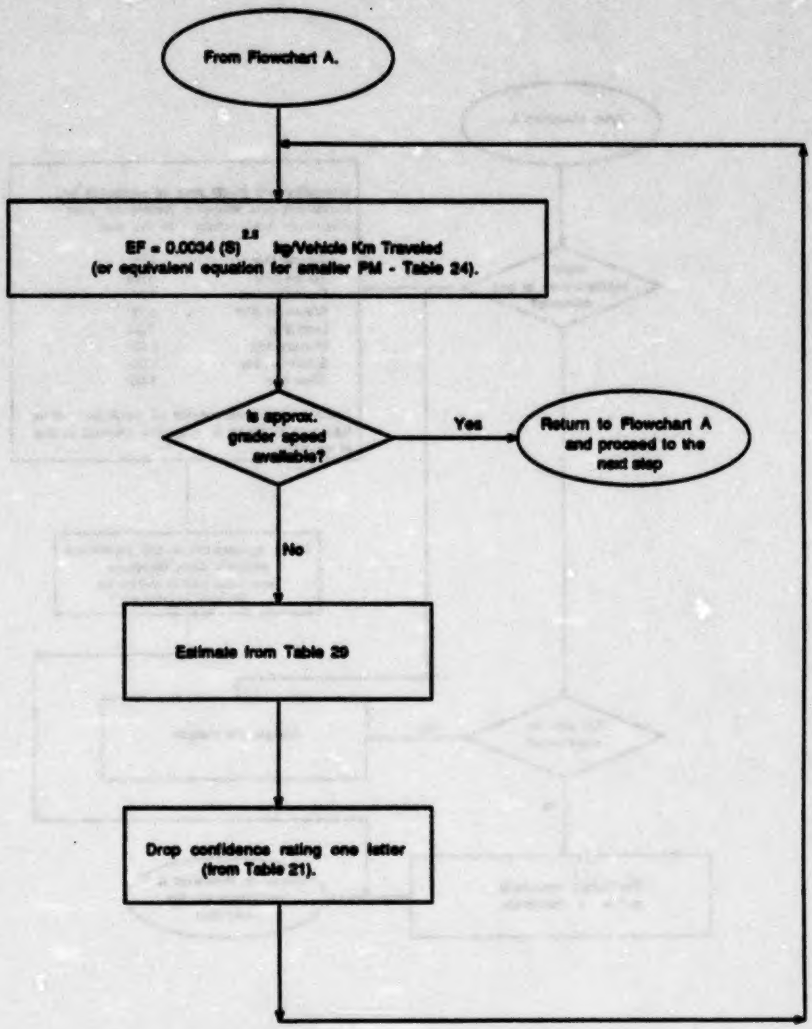

From Flowchart A.
EF = 0.0034 (S)^2.5 kg/Vehicle Km Traveled
(or equivalent equation for smaller PM - Table 24).
Is approx. grader speed available?
Yes
Return to Flowchart A and proceed to the next step
No
Estimate from Table 29
Drop confidence rating one letter (from Table 21).

Figure 19. Flowchart G: Estimating grading emissions.

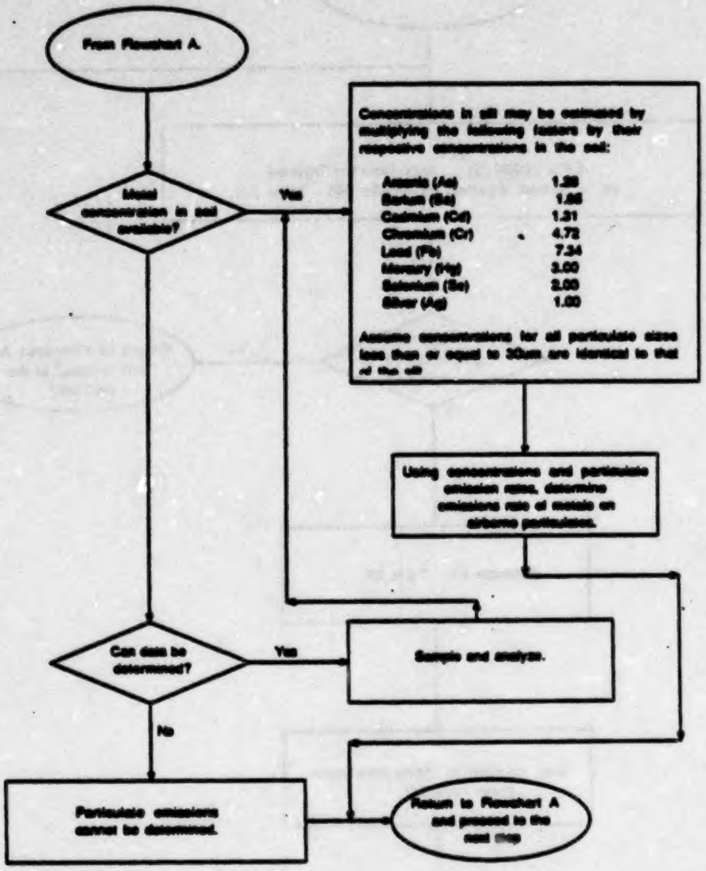

From Flowchart A.
Metal concentration in soil available?
Yes
Concentrations in silt may be estimated by multiplying the following factors by their respective concentrations in the soil:
Arsenic (As) 1.28
Barium (Ba) 1.66
Cadmium (Cd) 1.31
Chromium (Cr) 4.72
Lead (Pb) 7.34
Mercury (Hg) 3.00
Selenium (Se) 2.00
Silver (Ag) 1.00
Assume concentrations for all particulate sizes less than or equal to 30um are identical to that of the silt
Using concentrations and particulate emission rates, determine emissions rate of metals on airborne particulates.
Can data be determined?
Yes
Sample and analyze.
No
Particulate emissions cannot be determined.
Return to Flowchart A and proceed to the next step

Figure 20. Flowchart I: Determination of RCRA metal enrichment on fugitive particulate emissions.

Emission equations for particulate matter are available for each category, with the exception of the stabilization and solidification category, for which only factors (estimated from other industries) are available. The emission factor equations were summarized in Table 21. Definitions of the parameters used in the equations were given in Table 22. Typical values are shown in Tables 28 and 29. Local values for the soil parameters shown in Table 28 will also commonly be available from the Soil Conservation Service of the U.S. Department of Agriculture. A drawing of the continental U.S. and Alaska showing the average number of wet days per day ($\geq$0.254 mm precipitation) is included as Figure 21. This information is necessary for estimating particulate matter emissions from transport.

Since the emission equations for particulate matter are empirical equations, it is important that the site values of the parameters fall within the same range as the original data, upon which the equations are based. Values used to construct the equations are shown as ranges in Table 29. Specific data for the site of interest should be compared to these values. When site values fall outside the ranges given in Table 29, the confidence rating (from Table 21) should be dropped one letter. The ranges in Table 29 may also be used as typical values for equation parameters if no site-specific data are available.

Depending upon the remediation treatment employed at a particular site, some special considerations may have to be accounted for which are not obvious from the flowcharts in Section 3.6. For instance, the storage pile emissions category does not account for emissions caused by vehicle traffic between storage piles. The emission factor from this task should be calculated using the unpaved road equation found in the transportation category. The value for the silt content of the surface between the piles should be used if possible, rather than the value for the silt content of the material in the storage pile.

TABLE 28. TYPICAL VALUES OF PHYSICAL PROPERTIES FOR VARIOUS MATERIALS WITH RANGES IN PARENTHESES

Material	Moisture (%)	Silt Content (Wt. %)	Porosity (%)	Density (g/mL)	Reference
Exposed Ground[a]	ND	15.0 (5.1-21)	ND	ND	31
Topsoil[a]	ND	40	51	0.96	29/54
Sand[a]	ND	10	32	1.59	29/54
Limestone[a]	ND	2	ND	ND	29
Clay[a]	ND	ND	48	1.34	54
Haul Truck Material[b]	ND	364 (34-2270) lb/acre	ND	ND	31
Overburden					
Bulldozer	7.9 (2.2-16.8)	6.9 (3.8-15.1)	ND	ND	31
Dragline	3.2 (0.2-16.3)	ND	ND	ND	31
Scraper	ND	16.4 (7.2-25.2)	ND	ND	31
Rural Road					
Gravel	ND	5.0	ND	ND	31
Dirt	ND	28.5 (5.8-68)	ND	ND	31
Crushed Limestone	ND	9.6 (7.7-13)	ND	ND	31

[a] Local values of the physical parameters in this table will commonly be available from the U.S. Department of Agriculture's Soil Conservation Service.

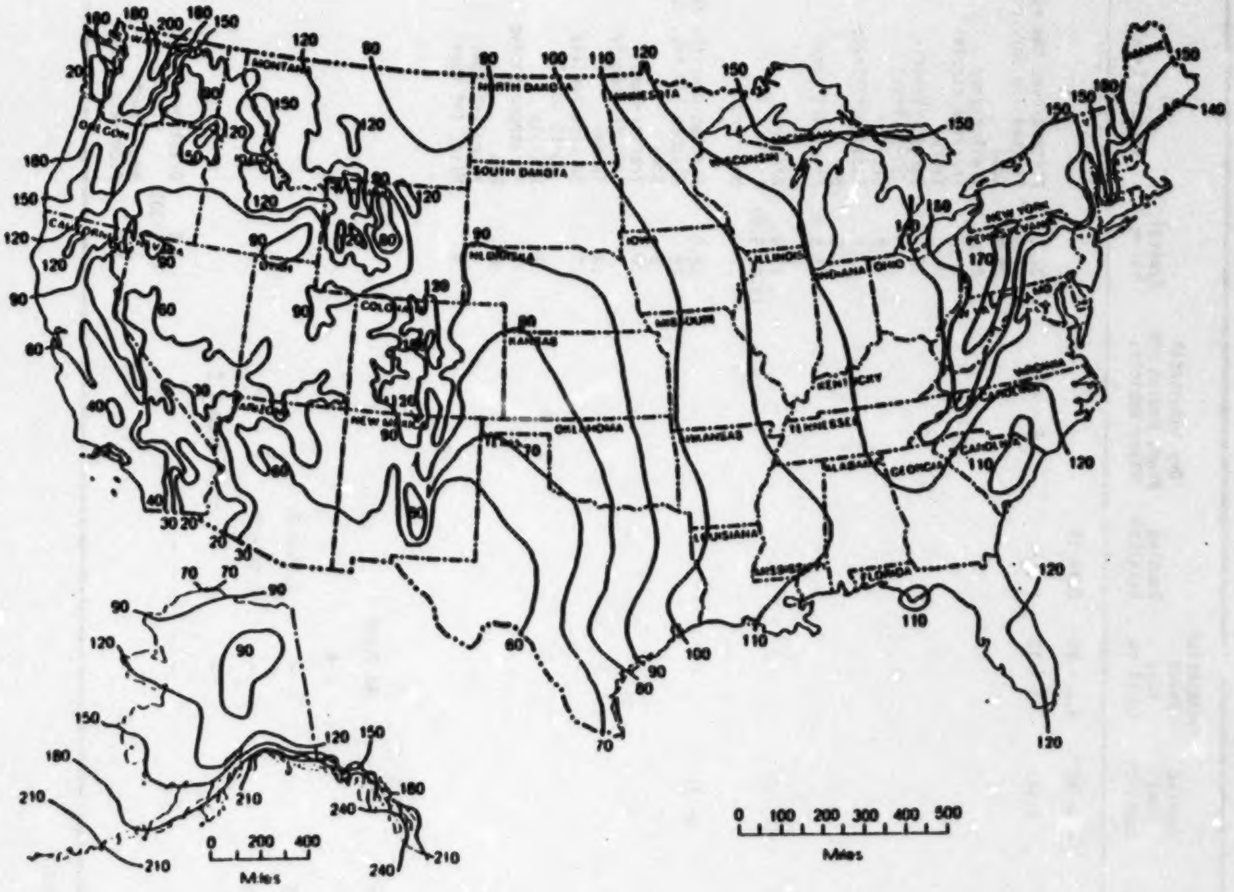
[b] Site loading, not silt fraction; given in lb/acre.

ND = no data.

TABLE 29. RANGES OF SOURCE CONDITIONS FOR TRANSPORT AND EXCAVATION EQUATIONS WITH TYPICAL VALUES BY VEHICLE TYPE

Parameter	Unit	Unpaved Road Equation	Industrial Paved Road Equation	Dumping Equation	Dry Industrial Road, Medium and Heavy Vehicles	Typical Value	Vehicle Type
s	wt %	4.3- 20	5.1 - 92	0.44-19	-		
W	mg	3-142	3 - 12	-	6 - 42	22.0	Flatbed-over the road
						51.3	Flatbed-low boy, coil
						23.0	Scow
						20.2	Trailer-dump
						11.2	Straddle carrier
						23.2	Tanker
						12.9	Service Vehicle (10-15 tons)
						6.8	Utility
						2.6	Passenger/Pickup
						7.9	Bus
						1.8	Misc. (<5 tons)
S	km/hr	21- 64	-	-	-	11.4 (8.0-19.0)	Grader
						32.0	Haul Truck
W	-	4- 31	-	-	-	18.0	Flatbed-over the road
						20	Flatbed-low boy, coil
						6	Scow
						20	Trailer-dump
						4	Straddle carrier
						18	Tanker
						10	Service Vehicle (10-15 tons)
						6	Utility
						4	Passenger/Pickup
						6	Bus
						4	Misc. (<5 tons)
						9	Misc. (>5 tons)
I	-	-	1	-	-		
L	kg/km	-	42-2,000	-	-		
n	-	-	2-4	-	-		
M	wt. %	-	-	0.25-4.8	-		
u	m/sec	-	-	0.58-6.7	-		
sL	g/m^2	-	-	-	0.02-0.2		
d	m	-	-	-	-	8.6 (1.5-30)	Dragline
						3	Haul Truck
						1.5	Front-End loader

- = not applicable.



MONTANA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
OREGON
IDAHO
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
NEW YORK
COLORADO
KANSAS
MISSOURI
KENTUCKY
NEW MEXICO
OKLAHOMA
ARKANSAS
TENNESSEE
ALABAMA
GEORGIA
LOUISIANA
FLORIDA
VIRGINIA
0 100 200 300 400 500
Miles
0 200 400
Miles

Figure 21. Mean number of days with ≥0.254 mm (0.01 in.) of precipitation per year.

Source: Reference 55.

Metal Emission Factors--

If metals adsorbed onto the surface of the particulates are of interest to the user, the flowchart shown in Figure 20 will enable the estimation of the enrichment of the RCRA metals: arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and silver (Ag). Only RCRA metals were studied in the report from which the enrichment ratios were taken (27).

Note that knowledge of the average concentration of these metals in the contaminated soil is necessary for this determination. Table 30 shows the concentrations of these metals in the silt samples from the original study. If no site-specific soil concentrations are available, the median silt concentrations in Table 30 may be used as gross estimates. These concentrations were obtained from only eight TSDF facilities, however, and are not necessarily representative of any particular site.

Control of Emissions--

First, controls for both particulates and organics should be selected for each category; a list of alternatives may be found in Table 12. Next, the emission factors should be adjusted from uncontrolled to controlled emissions. Control efficiencies for the technologies listed in Table 12 are summarized in Table 13. If information more specific or more accurate than that found in Table 13 is available, it should be used. The formula for calculating controlled efficiencies is the following:

$$XER_{i(\text{controlled})} = XER_{i(\text{uncontrolled})} \cdot (1-CE/100) \qquad \text{(Eq. 16)}$$

The controlled emission factor should be used for further analyses.

Conversion to Emission Rate--

After each category has been examined separately, then each emission factor will need to be converted to an emission rate (i.e., from emissions per mass, volume, mileage, or surface area of storage to emission per time). Finally, the contribution from all cells of waste should be summed to arrive at total VO, particulate, and metal emission factors. The total organic,

TABLE 30. METAL CONCENTRATION AND ENRICHMENT DATA

	Median Concentration in Silt (ug/g)	Median Enrichment Ratios Silt Conc. over Background Conc.
Arsenic (As)	8.7	1.28
Barium (Ba)	222	1.85
Cadmium (Cd)	4.9	1.31
Chromium (Cr)	142	4.72
Lead (Pb)	146	7.34
Mercury (Hg)	0.40	3.00
Selenium (Se)	0.90	2.00
Silver (Ag)	8.9	1.0
Number of Samples	26	26
Number of Sites Sampled	8	8

particulate or metal emissions from the remediation are the sum of all the respective emission rates. Calculating one overall rate allows comparison between different remedial alternatives.

The factors required for this conversion are shown in Table 31. Typical operating rates are shown in Table 32; however, if better estimates are available, they should be used instead. The conversion is described in greater detail in Appendix D, under Step 7 of the protocol.

One limitation of scaling the factors to a per day basis is that most of the equations are designed to estimate annual emissions rather than daily emissions. Particulate emissions can vary from day to day because of rainfall (hence moisture content) and in some cases, wind speeds. Seasonal variations may in some cases be accounted for with data from the National Weather Service, but only if the season in which remedial action will occur is known. If so, then the number of seasonal dry days can be compared to the number of annual dry days; a ratio of the two can be used to compensate the factor of (365-p)/365 or (365-p)/235 in the equations. Likewise, daily or seasonal wind speeds may be used in equations instead of yearly averages.

3.6.2 Data Assumptions and Limitations

Several of the equations, especially in the transportation and storage categories, were designed to provide long-term (i.e., annual) estimates of particulate emissions. Trying to break the emissions down to lbs/min, lbs/hr, or even lbs/day can result in a severe lack of reliability in the equations or estimates, since they were formulated on the supposition that yearly averages of rainfall and in some cases wind speed would be used. If enough meteorological information is available from the National Weather Service, it may be possible to offset the dependence on precipitation by determining the average number of dry days during the season when remedial action will most likely be instigated, and then adjusting the parameters

TABLE 31. CONVERSION OF EMISSION FACTORS TO EMISSIONS PER UNIT TIME

Emission Factor (EF) Units	Scaling Factor(s) Required[a]	To Determine Scaling Factor
Excavation		
kg/metric ton	Metric tons of material excavated/day	
kg/m^3	m^3 of material excavated/day	
VKT	Vehicle kilometers traveled by scraper/day	
Transport		
kg/VKT	Vehicle kilometers traveled/day	VMT = (miles traveled by each vehicle x(no. of vehicles)
kg/m^2·hour	Surface area covered by pile in truck (m^2). number of hours of transportation/day	
Dumping		
kg/metric ton	Metric tons dumped/day	(Capacity of vehicle)x(no. of dumps/day)x(no. vehicles)
Storage in Piles		
g/m^2·day	Area of surface covered by piles (not surface area of pile itself). 24 hr/day[b]	
g/m^2·day	Area of surface covered by piles	
Grading		
kg/VKT	Kilometers traveled by grading equipment/day	

[a] Equation is designated to give annual estimates. Emissions could vary between days because of rainfall (therefore moisture content of the soil).

[b] Equation probably overpredicts for 24-hour periods with low wind speeds: probably underpredicts for short periods and very high winds.

TABLE 32. TYPICAL OPERATING RATES FOR SOIL HANDLING ACTIVITIES

			Operation Frequency/Conversion Factor		
Remedial Option	Equipment Type	Bucket Capacity	To Obtain Maximum Emissions	To Obtain Average Emissions	Haul Distance
Excavation	Backhoe	0.8 m^3		275 m^3/day	-
		1.1 m^3	37 m^3		-
		2.7 m^3		920 m^3/day	-
	Dragline	0.8 m^3	120 m^3		-
		2.3 m^3		700 m^3/day	-
		15 m^3	390 m^3		
	Front-End Loader	2.3 m^3	-	-	-
	Scraper	11 m^3		600 m^3	460 m
		7.6 m^3		340 m^3	1500 m
	Dozer	4 m^3	250 m^3	1130 m^3/day	-
Dumping	Truck	5 m^3		180 m^3	400 m RT
		5 m^3		65 m^3	6500 m RT
		9.2 m^3		270 m^3	400 m RT
		9.2 m^3		24 m^3	32000 m RT

Source: EPA Handbook: Remedial Action at Waste Disposal Sites, EPA/625/6-85/006, References 26 and 43.

RT = Round trip distance.

Maximum emissions for 15 minute period.

(365-p)/365 and (365-p)/235 accordingly. Likewise, daily or seasonal wind speeds may be used in equations instead of yearly averages. Such adjustments (or use of assumed values) are particularly appropriate for evaluations of worst-case, short-term impacts.

Conversion of the emission factors to emission rates is dependent upon many parameters that will most likely have to be estimated: the mass of material in storage (which may or may not be less than the total excavated, depending upon the remediation employed), the number of vehicles needed for transportation, the acreage of storage space required, the distance between the excavation site and the storage area(s), etc. Estimation of these factors will certainly affect the reliability and accuracy of the emission estimates. However, this manual is designed to give only approximate estimates.

All of the emission factors and equations assume uniform contaminant concentration, moisture content, and silt fraction throughout the soil.

Determination of the enrichment of metal on silt particles ($\leq$75 um) was based on only one study of eight TSDFs (27). Only RCRA metals were considered, and concentrations varied significantly between sites. Also, concentrations of cadmium, arsenic, and selenium were below detection limits in more than half of the silt samples.

The unpaved road equation and other transportation equations do not account for emissions from the load carried by the vehicles. This was estimated using the short-term (24-hour) equation for wind erosion of a storage pile, where the wind speed in this case would be the sum of vehicle speed and wind speed. Instead of using the acreage of storage, the surface area of the vehicle bed should be used. It is assumed in this manual that covering the load, such as with a tarpaulin, would provide 100% control efficiency. These considerations are diagrammed in Figure 13.

3.7 SOLIDIFICATION/STABILIZATION

The process for estimating particulate matter solidification or stabilization is given as Figure 22. The emission factor data for the stabilization and solidification category are taken directly from other industries, since fugitive particulate emissions from these processes have not been studied. The emission factors for stabilization processes, which normally blend the waste with fly ash, cement or lime kiln dust, silicic materials, and/or lime, were taken from the batch concrete industry, as reported in Orlemann (29). The emission factors for solidification processes, which normally employ asphalt or hydrocarbon binding agents, were taken from the asphaltic concrete industry, as given in Orlemann (29). The accuracy of these estimates cannot be assessed at this time without actual emissions data from remedial activities.

Several other emission processes must be considered. Use of stabilization and solidification processes will more than likely require storage on-site of raw materials such as fly ash, aggregate for asphalt production, or silicic material. If these materials will be stored in piles, the contribution from these sources must be accounted for using the storage pile equations.

Furthermore, when stabilization or solidification processes are used, it should be noted that the emission factors as shown in Figure 22 include steps for the process only, such as mixing of the materials. Excavation, dumping into storage piles, and storage of soil and raw material must all be taken into account with the equations in Figures 15 through 19. Figure 22 gives the best estimate of everything from transfer of the materials (from the storage piles to the process), through production of the final solid product. Replacement of the material is shown in another block in Figure 22; this data point comes from replacement of overburden in western surface coal mining (31).

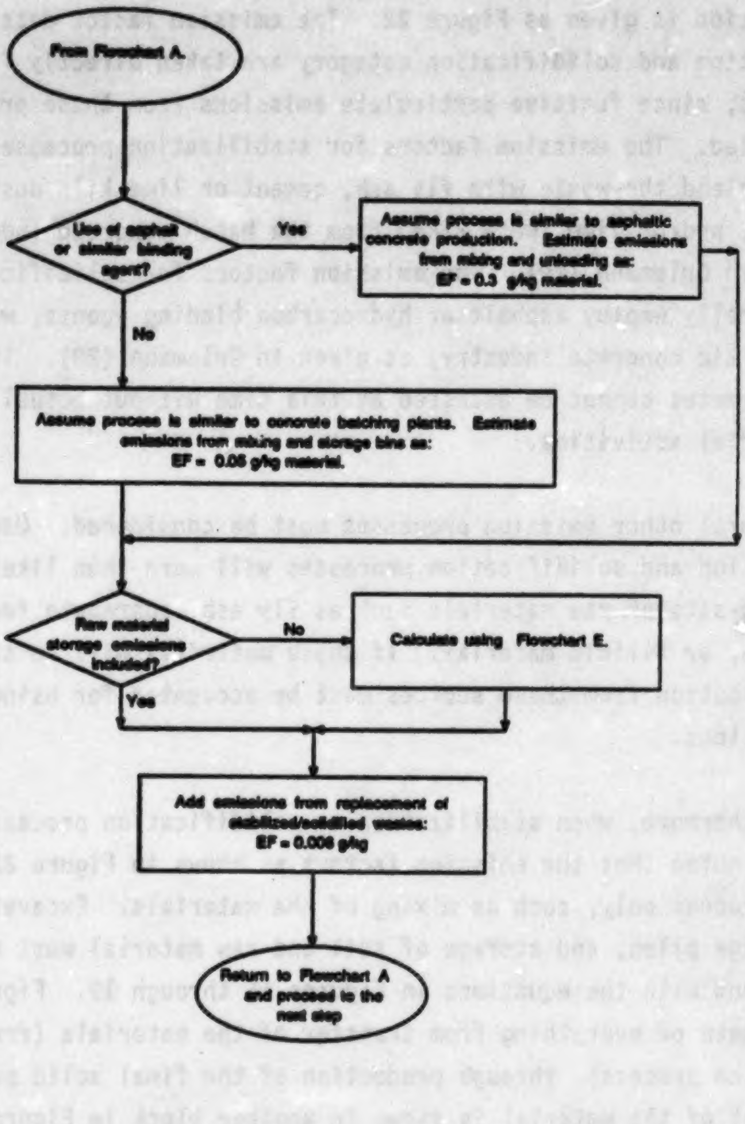

From Flowchart A.
Use of asphalt or similar binding agent?
Yes
Assume process is similar to asphaltic concrete production. Estimate emissions from mixing and unloading as: EF = 0.3 g/kg material.
No
Assume process is similar to concrete batching plants. Estimate emissions from mixing and storage bins as: EF = 0.05 g/kg material.
Raw material storage emissions included?
No
Calculate using Flowchart E.
Yes
Add emissions from replacement of stabilized/solidified wastes: EF = 0.006 g/kg
Return to Flowchart A and proceed to the next step

Figure 22. Flowchart H: Estimating solidification and stabilization emissions.

Volatile organic emissions from solidification/stabilization have not been extensively studied. An EPA pilot-scale study found roughly 10-60% of volatiles were driven off during mixing and curing (56).

3.8 NO ACTION/POST CLEAN-UP EMISSIONS

Under some circumstances, no action will be required at an NPL site or the type of remediation selected will not significantly increase the air emissions from the site. In such cases, the emissions will be equivalent to the baseline emissions for the undisturbed site. Baseline emissions can be estimated using the protocol presented in Volume II of this series (2). In many cases, the baseline emissions will be undetectable or too low to be a concern. Overburden and vegetation over the contaminants can act to attenuate or reduce air emissions. The upper layer of any organic waste contamination may also lose its volatile fraction over time and create a cap layer to reduce volatilization from underlying material.

Emissions after clean-up will vary depending on the remedial option selected, its application, and on the target endpoint. Again, the protocol presented in Volume II is the best approach for estimating post clean-up emissions. By definition, if the remediation is properly performed, then no post clean-up air problems will exist. In some cases, however, the treatment or removal activities will leave low-level residual contamination at a site in a state where post clean-up emissions may exceed the original baseline emissions, at least until further depletion occurs and the emission rates decay.

SECTION 4
EMISSIONS ESTIMATION EXAMPLE

This section presents a hypothetical NPL site and gives example calculations demonstrating the emissions estimation protocols from Section 3. The example represents a program in the pre-ROD stage, where various potential clean-up options are being evaluated.

4.1 SITE DESCRIPTION

No such thing as a "typical NPL site" exists, but the hypothetical site is meant to exhibit a combination of factors that are individually characteristic of many sites. The Erewhon Site is a 0.6 km^2 (160-acre) abandoned disposal area that is adjacent to an urban area. The site was used as a dumping place for many years and received a combination of acidic refinery sludge, used motor oil, and crushed batteries. The waste is uniformly found in a layer, 0.9 m (3 feet) thick, across 0.16 km^2 (40 acres) of the site. The waste is covered with a 0.6 m (2-foot) layer of overburden. Beneath the waste is a 4.6 m (15-foot) layer of unconsolidated silt and gravel. The depth to ground water is 6.1 m (20 feet). The site is located directly above a sole-source aquifer, with community drinking water wells located less than a mile down gradient. The nearest downwind receptors are about 1 kilometer away in the direction of the predominant winds.

The soil at the site is fairly uniformly contaminated across the entire 0.16 km^2 (40 acres). The overburden contains 0.5% volatile organic compounds (VOCs) and 10 ug/g lead. The waste itself is a black, asphalt-like material that contains 10% VOCs and 1000 ug/g lead. The soil beneath the waste layer is contaminated with organic vapors, with the soil pore space VOC content varying from 100,000 ppm near the ground-water table to 500 ppm directly below the waste layer. A hydrocarbon lens, 0.3 m thick, is present on top of the ground water. The water itself contains 10 mg/L VOCs (benzene).

The site RPM is initially considering a number of clean-up options. These include:

1. Removing the overburden and sending it for off-site disposal at a nearby (10 miles) hazardous waste disposal facility.

2. Digging up the waste layer and incinerating it on site.

3. Installing an in-situ venting system to treat the subsurface vapor contamination problem.

4. Removing the hydrocarbon lens, then using an air stripper to treat the contaminated ground water.

The RPM assigned a contractor to evaluate each option. One of the factors to be considered was the potential for significant air emissions.

4.2 PRELIMINARY ASSESSMENT OF EMISSIONS POTENTIAL

The contractor used the procedure given in Section 3.2 to do a preliminary assessment of the air emissions potential for the site. Section 3.2 lists eight possible site-related conditions, any one of which indicate that air emissions during remediation could be significant. All four scenarios meet one or more of these conditions due to the proximity of receptors, the handling of large volumes of contaminated material, and the potential for a large mass of uncontrolled emissions from treatment alternatives. This work indicated that air emissions were potentially a significant concern, so a more precise emissions estimate was developed. The estimate will focus on uncontrolled particulate matter emissions and controlled and uncontrolled VOC emissions since these are thought to be the greatest concerns based on the site description.

4.3 EMISSIONS ESTIMATE FOR SCENARIO ONE

The basic approach taken to determine emissions from soils handling is to divide the problem into four basic steps:

1. Calculate emissions of VOCs caused by soils handling;
2. Calculate emission factors for particulate emissions;
3. Determine operation data needed to convert emission factors to emission rates; and
4. Calculate emission rates in the desired units for use in dispersion modeling.

Emission factors and rates will be calculated for each of the following activities:

1. Excavation of soil overburden from the site;
2. Soil transport from the site to a hazardous waste facility 10 miles away;
3. Dumping of soil from trucks at the hazardous waste facility; and
4. Grading of the replacement soil after other remedial activities are completed.

Site parameters necessary for estimating emissions from soils handling are listed in Table 33, along with the assumed value.

TABLE 33. EREWHON SITE PARAMETERS (To estimate emissions from soil handling.)

Site area	160 acres
Contaminated area	40 acres
Depth of soil overburden	2 feet
Lead (Pb) concentration in soil overburden	10 ppmw
VOC concentration in soil overburden	0.5%
VOC baseline emissions	400 ug/m^2-min
Site terrain	Level
Nearest Downwind Receptors	0.25 mile
Number of days with >0.01 inches precipitation	140 days
Average wind speed	10 mph
Percent of time wind speed exceeds 12 mph (at midpoint of soil storage pile height)	20%
Site Overburden	
Silt content	10 wt. %
Moisture content	4 wt. %
Road Access	
Site is accessible by paved roads	
Distance from road to "hot" area	0.25 mile
Paved Road Information	
Silt content of paved roads	6 wt. %
Dust loading of paved surface	280 kg/km
Number of lanes of traffic	2 lanes

4.3.1 VOC Emissions from Soils Handling

The site RI/FS found the average VOC emission rate from the undisturbed contaminated soil (not the exposed waste) to be 400 ug/m^2·min. For the 0.16 km^2 site, this results in baseline emissions of 3.84 kg/hr.

Excavation--

From Table 27, the average increase in emissions (agitation factor) due to excavation using a bulldozer is 50. Therefore, the VOC emission rate during excavation is:

$$EF = (400\ \mathrm{ug/m^2 \cdot min})(50)$$
$$EF = 20{,}000\ \mathrm{ug/m^2 \cdot min}$$
$$= 0.02\ \mathrm{g/m^2 \cdot min}$$

Assume that: (1) each truck has 17 m^2 of exposed soil; (2) one truck at a time is filled and the soil is exposed for 15 minutes; and (3) the exposed waste beneath the topsoil is covered with an impermeable barrier after the soil is removed or immediately excavated and hauled to the incinerator.

$$EF = (0.02\ \mathrm{g/m^2 \cdot min})(17\ \mathrm{m^2})(15\ \mathrm{min})$$
$$= 5.1\ \mathrm{g\ VOC\ per\ truck\ load}$$

It is estimated later in this section that 124 truck loads a day will be required for 88 working days (8-hours each) to remove all the contaminated soil. This corresponds to emissions of:

$$\text{Daily Emissions} = (5.1\ \text{g VOC/truck load})(124\ \text{truck loads/day})$$
$$= 632\ \text{g VOC/day or } 0.079\ \text{kg/hr}$$

$$\text{Total Emissions} = (632\ \text{g VOC/day})(88\ \text{days})$$
$$= 55{,}700\ \text{g VOC}$$
$$= 55.7\ \text{kg VO}$$

From Table 13, temporary foams could be used for temporary emissions control with 81% effectiveness. This would reduce emissions to:

$$(0.079 \text{ kg/hr})[(100-81)/100] = 0.015 \text{ kg/hr}$$

Transport--

The trucks will certainly be covered during transport for dust and odor control. Controlled emissions can be assumed to equal zero. Uncontrolled emissions would depend on the length of the trip (assumed to be 2 hours for this site).

$$\begin{aligned} EF &= (0.02 \text{ g/m}^2\cdot\text{min})(17 \text{ m}^2)(120 \text{ min}) \\ &= 40.8 \text{ g VOC/truck load} \end{aligned}$$

This corresponds to 5,060 g VOC/day (0.63 kg/hr) and 445 kg VOC for the 88-day project.

Dumping--

From Table 27, the average increase in emissions (over the baseline emission rate) due to dumping is 57. The emissions were already enhanced by excavating, but since this agitation factor is larger, the new higher emission factor will be used:

$$\begin{aligned} EF &= (400 \text{ ug/m}^2\cdot\text{min})(57) \\ &= 22{,}800 \text{ ug/m}^2\cdot\text{min} \end{aligned}$$

Assume that the soil will occupy the same 0.16 km^2 at the landfill as it did at the site (i.e., it is spread as a thin layer). The emissions will stay elevated for up to 4 days according to the storage data in Table 27. Assume a linear decay in emissions over the four days back to the baseline emission rate.

$$\begin{aligned} EF &= \frac{(400 \text{ ug/m}^2\cdot\text{min} + 22{,}800 \text{ ug/m}^2\cdot\text{min})}{2}(4 \text{ days})(1440 \text{ min/day}) \\ &= 6.68 \times 10^7 \text{ ug/m}^2 \\ &= 66.8 \text{ g/m}^2 \end{aligned}$$

$0.16\ km^2 = 160{,}000\ m^2$, so the total VOC emissions from dumping are:

$$\begin{aligned}\text{Total Emissions} &= (66.8\ g/m^2)(160{,}000\ m^2)\\ &= 1.07 \times 10^7\ g\ VOC\\ &= 10{,}700\ kg\ VOC\end{aligned}$$

Assuming the soil is dumped equally over 88 consecutive working days, the daily VOC emission rate due to dumping is:

$$\begin{aligned}\text{Daily Emissions} &= (10{,}700\ kg)(1/88\ days)\\ &= 122\ kg/day\ \text{or}\ 5.1\ kg/hr\end{aligned}$$

From Table 13, stabilized foams can achieve 99% vapor control efficiency. So, the controlled emissions would be 1% of the uncontrolled emissions, i.e., 0.152 kg/hr and 107 kg total. In actual practice, complete coverage by foams is not usually possible and emissions will probably be higher.

Grading--

The increase in emissions due to grading can range from 2 to 38 times the baseline emission rate. Even the highest value is less than the increase due to dumping. So, if the soil is graded within 1-2 days after dumping, grading is not expected to significantly increase the already elevated emission rates.

4.3.2 Particulate Emission Factors from Soils Handling

The first step in estimating particulate emissions is to determine the particle size of interest. Since the soil is contaminated with lead, both downwind receptor concentrations and worker exposure concentrations are needed. Emission rates of particulates <30 um in diameter are required for downwind receptor modeling and worker safety. In addition, emission rates of inhalable particulates (<15 um) are necessary to determine worker safety hazards. Inhalable emissions will be estimated for all appropriate on-site activities. Equations shown are from Table 21 unless otherwise specified.

Excavation--

1. Equipment used: one bulldozer for the 40 contaminated acres.

2. Emission factor for TSP, <30 um:

$$EF = 2.6(s)^{1.2}(M)^{-1.3} \text{ kg/hr}$$

s = wt % silt = 10
M = wt % moisture = 4

$$EF = 2.6(10)^{1.2}(4)^{-1.3}$$
$$= 6.8 \text{ kg/hr}$$

3. Emission factor for inhalable particulate, <15 um:

$$EF = 0.45(s)^{1.5}(M)^{-1.4} \text{ kg/hr} \qquad \text{(Table 28)}$$
$$= 0.45(10)^{1.5}(4)^{-1.4}$$
$$= 2.0 \text{ kg/hr}$$

Soil Transport--

Contaminated soil will require transport to a secure hazardous waste disposal site. This site is 10 miles away and will require driving on 0.25 mile of unpaved roads (across part of the 160-acre site without a contaminated soil surface) to the nearest paved road. The remainder of the journey, 9.75 miles, is on paved roadways. In addition, the trucks will have to drive on the contaminated surface to retrieve the soil from the excavation equipment. The average distance traveled per truck across contaminated soil is 0.2 mile round-trip (RT).

1. Equipment used: trucks with a 12 cubic yard capacity, 6 wheels, and weighing 36 Mg.

2. Transport over contaminated soil: 0.2 mile RT. Use unpaved road equation and contaminated soil characteristics. Average truck speed

is 10 mph (16 km/hr). Calculate EF for TSP and inhalable particulates.

$$EF = k(1.7)(s/12)(S/48)(W/2.7)^{0.7}(w/4)^{0.5}(365 - p)/p \text{ kg/VKT}$$

k = particle size multiplier = 0.8 for <30 um
k = particle size multiplier = 0.5 for <15 um
s = silt content, wt % = 10
S = average truck speed, km/hr = 16
W = average weight of truck, M = 36
w = number of wheels = 6
p = number of wet days/year = 140

$$EF = 0.8(1.7)(10/12)(16/48)(36/2.7)^{0.7}(6/4)^{0.5}(365 - 140)/140$$
$$= 4.6 \text{ kg/VKT for TSP, } <30 \text{ um}$$

$$EF = 0.5(1.7)(10/12)(16/48)(36/2.7)^{0.7}(6/4)^{0.5}(365 - 140)/140$$
$$= 2.8 \text{ kg/VKT for inhalable particulate, } <15 \text{ um}$$

3. Transport on unpaved "roads," over uncontaminated site soil. Use site soil characteristics. Average truck speed is 10 mph (16 km/hr), 0.5 mile RT. Only TSP emissions are of interest. Since all parameters are the same as for contaminated soil, with the exception of the metals and VOC content, the emission factor is the same:

$$EF = 0.8(1.7)(10/12)(16/48)(36/2.7)^{0.7}(6/4)^{0.5}(365 - 140)/140$$
$$= 4.6 \text{ kg/VKT for TSP, } <30 \text{ um}$$

4. Transport on paved roads, 19.5 miles RT. Silt content of the road shoulders is 6%. Assume that since the nearest downwind receptors are only 0.25 mile away, it is an urban area, and most or all of the roads in the area are paved. Average truck speed is 35 mph (57 km/hr).

$$EF = 0.022(I)(4/n)(s/10)(L/280)(W/2.7)^{0.7} \text{ kg/VKT}$$

I = industrial augmentation factor, explained in Table 26= 1.0
n = number of traffic lanes = 2
s = silt content, wt % = 6
L = surface dust loading, kg/km = 280
W = average weight of truck, Mg = 36

$$EF = 0.022(1)(4/2)(6/10)(280/280)(36/2.7)^{0.7}$$
$$= 0.162 \text{ kg/VKT}$$

5. Emissions from truck bed during transport: uncontrolled.

$$EF = 0.0018(u) \text{ kg/hr per square meter of surface area}$$

u = sum of vehicle speed and wind speed, m/sec
35 mph + 10 mph = 45 mph
45 mph * (hr/3600 sec)(1000 m/0.62 mile) = 20 m/sec

$$EF = 0.0018(20) \text{ kg/hr m}^2$$
$$= 0.036 \text{ kg/hr m}^2$$

10 mph + 10 mph = 20 mph = 9.0 m/sec

$$EF = 0.0018(9) = 0.016 \text{ kg/hr m}^2$$

From Tables 23 and 25, no information is available on particle size multipliers for this application. Assume that the multiplier for dumping applies here, such that k = 0.50 for particulates ≤15 um. The emission factor for the inhalable particulates is thus:

$(0.5)(0.036) = 0.018$ kg/hr m^2 at 35 mph
$(0.5)(0.016) = 0.008$ kg/hr m^2 at 10 mph

Controlled emissions for transportation can be assumed to be zero.

Dumping--

Since the contaminated soil will be transported to another disposal site, the emissions from dumping will not occur at the clean-up site, but rather at the other site. However, emissions of both total and inhalable particulate are of interest at the other site, which has downwind receptors no closer than 10 kilometers away.

$$EF = k(0.0016)(U/2.2)^{1.3}(M/2)^{-1.4} \text{ kg/Mg dumped}$$

k = particle size multiplier = 0.74 for <30 um
k = particle size multiplier = 0.48 for <15 um
U = mean wind speed, m/sec = 4.5 (10 mph)
M = moisture content, wt % = 4

$$\begin{aligned} EF &= 0.74(0.0016)(4.5/2.2)^{1.3}(4/2)^{-1.4} \\ &= 0.0011 \text{ kg/Mg dumped, TSP <30 um} \end{aligned}$$

$$\begin{aligned} EF &= 0.48(0.0016)(4.5/2.2)^{1.3}(4/2)^{-1.4} \\ &= 0.00074 \text{ kg/Mg dumped, inhalable <15 um} \end{aligned}$$

Storage--

Since the soil is not being stored on site, no storage piles will be required.

NOTE: In circumstances where the emissions from storage piles are important, the surface area per pile referred to is not the surface area of the pile itself, but rather is the surface area covered by the pile (e.g., a storage pile covering 0.5 acre of land).

Grading--

The contaminated soil will not be graded on site, but will be graded after it is dumped at the certified hazardous waste disposal site. The total and inhalable particulate emissions are of interest there.

1. TSP:

$EF = 0.0034(S)^{2.5}$ kg/VKT

S = average grader speed, km/h = 11.4 (Table 29)

$EF = 0.0034(11.4)^{2.5}$

$= 1.5$ kg/VKT

2. Inhalable particulate, 15 um

$EF = 0.0056(S)^{2.0}$ kg/VKT (Table 24)

$EF = 0.0056(11.4)^{2.0}$

$= 0.73$ kg/VKT

4.3.3 Particulate Emission Rates from Soils Handling

Conversion of emission factors to emission rates is dependent upon the operations at the site: the number of bulldozers and trucks, the distance over which the soil is transported, etc. Calculate all the necessary operating parameters, then calculate emissions per hour and emissions per day (assuming 8 hours of emissions per day).

Excavation--

One bulldozer used for the 40-acre site.

Bucket capacity: 5 yd^3

Avg daily load: 1480 yd^3/day (Table 18)

Volume of 40 acres with 2 feet of soil overburden:

$(40 \text{ acre})(43{,}560 \text{ ft}^2/\text{acre})(2 \text{ ft})(\text{yd}/3 \text{ ft})^3 = 129{,}000 \text{ yd}^3$

At 1480 yd^3/day, number of days for excavation:

$129,000\ yd^3/1480\ yd^3/day = 87.2\ days = 88\ days$

TSP Emission Rate:

ER = 6.8 kg/hr * 1 bulldozer = 6.8 kg/hr

ER = 6.8 kg/hr * 8 hr/day * 1 bulldozer = 54.4 kg/day

Inhalable Particulate Emission Rate:

ER = 2.0 kg/hr * 1 bulldozer = 2.0 kg/hr

ER = 2.0 kg/hr * 8 hr/day * 1 bulldozer = 16.0 kg/day

Soil Transport--

Assume that trucks are not the limiting factor, but that enough trucks will be available to carry away all contaminated soil as it is excavated. Since each truck's capacity is 12 yd^3, the number of loads per day required would be:

$(1480\ yd^3/day)/(12\ yd^3/load) = 123.333 = 124\ loads/day$

Since each trip will require 0.7 mile at 10 mph and 19.5 miles at 35 mph (1.1 km at 16 km/hr and 31.5 km at 57 km/hr), the number of trips required, and therefore the number of trucks (at 12 yd^3 capacity each), is estimated as follows:

(0.7/10) + (19.5/35) hours = 0.63 hours

Drivers will also require time for traffic signals, dumping, and decontamination at both sites; therefore, allow 2 hours per trip.

(8 hours/day)/(2 hours/trip) = 4 trips/day per truck
(124 loads/day)/(4 trips/truck/day) = 31 trucks/day

Vehicle kilometers traveled (VKT), and likewise vehicle miles traveled (VMT), refers to the sum of the distances traveled along the road of interest by all vehicles traveling that road. Since three types of "road" surfaces are employed (contaminated soil, uncontaminated soil, and paved roads), the total kilometers (miles) traveled should be calculated for each surface.

Contaminated soil:

0.2 mile (0.3 km) for each round trip (RT) at an average speed of 10 mph (16 km/hr)

0.3 km/trip * 124 trips/day = 37 VKT/day

Uncontaminated soil/unpaved road:

0.5 mile (0.8 km) per RT at an average speed of 10 mph (16 km/hr)

0.8 km/trip * 124 trips/day = 99 VKT/day

Paved road:

19.5 miles (31.5 km) per RT at an average truck speed of 35 mph (57 km/hr)

31.5 km/trip * 124 trips/day = 3910 VKT/day

The emission rate for particulates lost from the bed of the truck during transportation are dependent upon the surface area of the soil in the truck. Assuming a 12 yd^3 (9 m^3) pile which is hemispherical in shape:

$$V = 0.5(4\pi R^3)/3$$
$$9 = 0.5(4\pi R^3)/3 \text{ -----> } R = 1.6 \text{ m}$$
$$A = 0.5(4\pi R^2) = 17 \text{ m}^2$$

However, the truck is not always loaded, not always moving, and not always moving at the same average speed:

0.7 mile at 10 mph, 19.5 miles at 35 mph
4 trips per day per truck
31 trucks
loaded 50% of the time

(0.7/10) x 4 x 31 x 0.5 = 4.34 hr/day at 10 mph

(19.5/35) x 4 x 31 x 0.5 = 34.5 hr/day at 35 mph

$$ER = [(0.016\ kg/hr\ m^2)(4.34\ hr/day) + (0.036\ kg/hr\ m^2)(34.5\ hr/day)](17\ m^2)$$
$$= 25\ kg/day\ uncontrolled\ emissions$$

(25 kg/day)(day/8 hr) = 3.1 kg/hr

EF, Contaminated Soil, <15 um: 2.8 kg/VKT * 37 VKT/day
= 104 kg/day

(104 kg/day)/(8 hr/day) = 13 kg/hr

Dumping--

To convert the emission factor to an emission rate, estimate the mass of soil dumped at the new site. Use a bulk density of 1.5 g/cm^3, which is equal to 1.5 Mg/m^3. Recall that the volume of soil excavated by the bulldozer is 1480 yd^3 per day.

$$(1480\ yd^3/day)(0.9144\ m/yd)^3(1.5\ Mg/m^3) = 1700\ Mg/day$$

Therefore, the emission rate is:

(0.0011 kg/Mg)(1700 Mg/day) = 1.9 kg/day of TSP
(0.00074 kg/Mg)(1700 Mg/day) = 1.3 kg/day of <15 um particulate

On a mass per hour basis, assuming an 8-hour workday:

(1.9 kg/day)/(8 hr/day) = 0.24 kg/hr of TSP

(1.3 kg/day)/(8 hr/day) = 0.16 kg/hr of <15 um

In reality, all of the emissions would take place in a few minutes during and after each dump.

Grading--

The emission factor is in units of kg/VKT (vehicle kilometers traveled). The average speed of the grader is 11.4 km/hr (from Table 29). The length of an average work day is about 8 hours, but a significant amount of time will be required for stops and starts, since several trucks will be dumping small loads, and the grader will be spreading them over a small land area. Therefore, assume that the VKT may be estimated based on four hours a day at 11.4 km/hr:

11.4 km/hr * 4 hr/day = 46 km/day

The emission rates may then be calculated:

1.5 kg/VKT * 46 km/day = 69 kg/day TSP

69 kg/day * day/8 hours = 8.6 kg/hour TSP

0.73 kg/VKT * 46 km/day = 33 kg/day of <15 um

33 kg/day * day/8 hours = 4.1 kg/hour of <15 um

Summary of PM Emission Results--

Emission factors, rates, and conversion factors may be summarized in a table and totaled, as shown in Tables 34 and 35. Controlled emissions may be calculated by looking up the appropriate control efficiency (CE) in Table 13 and using it as follows:

$$\text{Controlled Emissions}_{(kg/hr)} = \text{Uncontrolled Emission Rate (kg/hr)} \; \frac{100-CE}{100}$$

Lead Emissions - Soil Handling--

Lead content of soil = 10 ppm

Lead content of silt ($\leq$75 um) = (10 ppm)(7.34) = 73.4 ppm

Assume that 73.4 ppm is the concentration of lead associated with all fugitive particulate emissions from soil handling.

1. Lead associated with TSP emissions per 8-hour workday:

Excavation = (54 kg TSP/day)(73.4×10^{-6} kg Pb/kg TSP)
= 4.0×10^{-3} kg Pb/day
= 5×10^{-4} kg Pb/hr

Transportation (truck bed losses and soil transport over contaminated soil)

Over contaminated soil = (169 kg/day)(73.4×10^{-6} kg Pb/kg TSP)
= 1.2×10^{-2} kg Pb/day

From truck bed = (4.9 kg/day)(73.4×10^{-6} kg Pb/kg TSP)
= 3.6×10^{-4} kg Pb/day

Dumping = (1.9 kg/day)(73.4×10^{-6} kg Pb/kg TSP)
= 1.4×10^{-4} kg Pb/day

Grading = (69 kg/day)(73.4×10^{-6} kg Pb/kg TSP)
= 5.1×10^{-3} kg Pb/day

Total = 2.2×10^{-2} kg Pb/day

TABLE 34. SUMMARY - EMISSIONS FROM SOILS HANDLING AT EREWHON SITE, FOR TOTAL SUSPENDED PARTICULATE (TSP, <30 um)

Type of Operation	Emission Factor	Conversion Factor	Emission Rate kg/day	Emission Rate kg/hour
Excavation	6.8 kg/hr	1 dozer	54	6.8
Soil Transport				
Contaminated soil	4.6 kg/VKT	37 VKT/day	169	21
Unpaved roads	4.6 kg/VKT	99 VKT/day	451	56
Paved roads	0.16 kg/VKT	3906 VKT/day	633	79
From truck bed	0.052 kg/hr m^2	17 m^2, 38.8 hr/day	25	3
Dumping	0.0011 kg/Mg	1700 Mg/day	1.9	0.24
Storage	N/A	N/A	N/A	N/A
Grading	1.5 kg/VKT	46 km/day	69	8.6
		Total	1402	175

TABLE 35. SUMMARY - EMISSIONS FROM SOILS HANDLING INHALABLE PARTICULATE (<15 um)

Type of Operation	Emission Factor	Conversion Factor	Emission Rate kg/day	Emission Rate kg/hour
Excavation	2.0 kg/hr	1 dozer	16	2.0
Soil Transport				
Contaminated soil	2.8 kg/VKT	47 VKT/day	104	13
Unpaved roads	---	---	---	---
Paved roads	---	---	---	---
From truck bed	0.026kg/hr m^2	17 m^2, 38.8 hr/day	17	2
Dumping	0.00074 kg/Mg	1700 Mg/day	1.3	0.16
Storage	N/A	N/A	N/A	N/A
Grading	0.73 kg/VKT	46 km/day	33	4.1
		Total	171	21

2. Lead associated with inhalable particulate emissions, ≤15 um:

Excavation = (16 kg/day)(73.4×10^{-6} kg Pb/kg)
= 1.2×10^{-3} kg Pb/day

Transportation

Over uncontaminated soil = (104 kg/day)(73.4×10^{-6} kg Pb/kg)
= 7.6×10^{-3} kg Pb/day

Dumping = (1.3 kg/day)(73.4×10^{-6} kg Pb/kg)
= 9.5×10^{-5} kg Pb/day

Grading = (33 kg/day)(73.4×10^{-6} kg Pb/kg)
= 2.4×10^{-3} kg Pb/day

Total = 1.1×10^{-2} kg Pb/day

4.4 EMISSIONS ESTIMATE FOR SCENARIO TWO

Incineration emissions fall into three categories:

- Waste handling emissions;
- Stack emissions; and
- Fugitive emissions.

Emission estimates for each of these three categories are developed below.

4.4.1 Waste Handling Emissions

The waste layer extends over 0.16 km^2 and is 0.9 m thick. Assume the waste will be removed concurrently with the soil removal by a second bulldozer, and transported to a location on site and dumped onto one large storage pile. The waste volume is 161,900 m^3 and according to Table 18, a bulldozer can excavate 1100 m^3 of material per day. Hence:

$$\text{Days of Waste Removal} = (161{,}900\ \text{m}^3)/(1100\ \text{m}^3/\text{day})$$
$$= 147\ \text{days}$$

Emissions of VOCs and particulate matter will be of concern, with VOC emissions almost certainly requiring some control measures.

The waste handling can be divided into excavation, transport, dumping, and storage steps.

Excavation, Transport, and Dumping--

The calculation of VOC and particulate matter emissions is analogous to the steps used in Section 4.3 for soils handling, with the physical and chemical characteristics of the material being different in some cases and requiring different input values, e.g., silt content. It is important to remember that excavation and dumping steps may be repeated to move waste from the storage pile onto the feed mechanism of the incinerator.

Storage--

Emissions for particulate matter and VOCs are estimated.

Storage pile particulate matter emissions (waste)--

Density = 1.5 g/cm^3 = 1.5 Mg/m^3
Silt content = 1% = s
Storage pile size = 0.5 acre
% time that unobstructed wind speed is greater than 12 mph at mid-point = 20% = f
Particle sizes of interest = $\leq$30 um and $\leq$15 um

1. Emission factor:

$$\text{EF} = 1.9(s/1.5)[(365 - f)/235](f/15)\ \text{kg/day/hectare}$$
$$= 1.9(1.0/1.5)[(365 - 140)/235](20/15)$$
$$= 1.6\ \text{kg/day/hectare}$$

2. Surface area occupied by pile = 0.5 acre:

(0.5 acre)(hectare/2.417 acres) = 0.20 hectare

3. Emission rate:

(1.6 kg/day/hectare)(0.2 hectare) = 0.32 kg/day
(0.32 kg/day)(day/24 hr) = 0.013 kg/hr

or, if the wind dies at night, assuming 12 hr of darkness:

(0.32 kg/day)(day/12 hr) = 0.03 kg/hr

Storage pile VOC emissions (waste)--

The site RI/FS found the average VOC emission rate from the exposed waste to be 10,000 ug/m^2·min. If all 0.16 km^2 of the waste was exposed, this would result in emissions of 96 kg/hr. This high value is consistent with the 10% VOCs in the waste. Assume that the waste pile is one-half of a sphere that has a radius of 42.6 m. The surface area would then be 11,400 m^2. The emission rate is:

$$\begin{aligned}\text{VOC Emission Rate} &= (10{,}000\ \text{ug/m}^2\cdot\text{min})(11{,}400\ \text{m}^2)(60\ \text{min/hr}) \\ &= 6.84 \times 10^9\ \text{ug/hr} \\ &= 6.84\ \text{kg/hr}\end{aligned}$$

This value would decrease over time as the pile shrunk in size. More importantly, the outer layer of waste would become depleted of VOCs over time and inhibit further volatilization from the waste underneath it. A worst-case scenario would be that the emissions stayed constant over the entire 5060 days required to incinerate the waste. Assuming a linear decrease in surface area of the pile over time, the average surface area would be:

$$\frac{11{,}400\ \text{m}^2 + 0\ \text{m}^2}{2} = 5700\ \text{m}^2$$

The worst-case total VOC emissions from storage are:

$$\begin{aligned}\text{Total Emissions} &= (10{,}000\ \text{ug/m}^2\cdot\text{min})(5700\ \text{m}^2)(1440\ \text{min/day})(5060\ \text{days}) \\ &= 4.15 \times 10^{14}\ \text{ug} \\ &= 4.15 \times 10^{5}\ \text{kg VOC}\end{aligned}$$

This value represents 1.7% of the total VOCs present in the waste. Emissions control up to 99% could be obtained using stabilized foam, physical covers, or by enclosing the waste in a building.

4.4.2 Stack Emissions

The pertinent input parameters are listed in Table 36.

Emissions from incineration and destruction efficiency are directly dependent on the design of the incineration system. For this example, it is assumed that optimum values have been selected for:

- Combustion gas flow rates;
- Auxiliary fuel requirements;
- Incinerator size;
- Burner size;
- Refractory dimensions; and
- Incinerator cost.

The controlled and uncontrolled emissions are estimated using the equations and/or assumed values from Section 3.3.

4.4.3 Organic Compounds

Assume that no control devices will be used that affect VOC emissions. From Equation 3:

$$\begin{aligned}ER_i &= [1 - (DRE/100)](C_i)(M_w)(1/1000) \\ &= [1 - (99.99/100)](100\ \text{g/kg})(2000\ \text{kg/hr})(0.001\ \text{kg/g}) \\ &= 0.02\ \text{kg/hr}\end{aligned}$$

TABLE 36. SITE PARAMETERS

Waste Parameters	
Volume	161,900 m^3 (193,600 yd^3)
Density	1.5 g/cm^3 = 1,500 kg/m^3
Mass	2.43 x 10^8 kg
VOC Concentration	10% = 150 kg/m^3
Pb Concentration	1000 ppm (ug/g) = 1.5 kg/m^3
S Concentration	1% = 15 kg/m^3
Btu Content	23.2 kJ/g (10,000 Btu/lb)
Incinerator Parameters	
Type	Rotary Kiln
Exhaust Gas Rate	125 m^3/min
DRE	99.99%
Feed Rate	2000 kg/hr

Assuming that the incinerator operates 24 hr per day, the daily emissions would be 0.48 kg/day. At the specified flow rate, the incinerator would need to be operated 5060 days to destroy all the waste. Thus, the total organic emissions would be 2430 kg.

4.4.4 Particulate Matter (PM)

From Section 3.3.2, typical uncontrolled PM emissions are 11,800 mg/m^3, controlled PM emissions are 72 mg/m^3, and RCRA performance standards limit PM emissions to a maximum of 180 mg/m^3. Assuming an exhaust gas rate of 125 m^3/min, emission would be:

$$\begin{aligned}\text{Uncontrolled} &= (11{,}800\ \text{mg/m}^3)(125\ \text{m}^3/\text{min})(\text{kg}/10^6\ \text{mg})\\ &= 1.475\ \text{kg/min}\\ &= 88.5\ \text{kg/hr}\end{aligned}$$

$$\begin{aligned}\text{Controlled} &= (72\ \text{mg/m}^3)(125\ \text{m}^3/\text{min})(\text{kg}/10^6\ \text{mg})\\ &= 0.009\ \text{kg/min}\\ &= 0.54\ \text{kg/hr}\end{aligned}$$

4.4.5 Metal Emissions

From Equation 5:

$$ER_i = (C_i)(M_w)(\%MF/100)$$

%MF (metal emissions as a percentage of input metal mass) values for lead are found in Table 20 and are 71% for uncontrolled emissions and average 26% for controlled emissions. Thus,

$$\begin{aligned}\text{Uncontrolled} &= (1\ \text{g/kg})(2000\ \text{kg/hr})(71/100)\\ &= 1420\ \text{g/hr}\\ &= 1.42\ \text{kg/hr}\end{aligned}$$

Controlled = (1 g/kg)(2000 kg/hr)(26/100)
= 520 g/hr
= 0.52 kg/hr

4.4.6 Acid Gas Emissions

From Equation 6, uncontrolled emissions are:

$ER_i = (C_j/1000)(R_i/j)M_w)$

$ER_i = (10\ g/kg)(1)(2000\ kg/hr)$
$= 20{,}000\ g/hr$
$= 20\ kg/hr$

From Table 13, dry injection and fabric filter controls are 50% effective. Therefore, uncontrolled emissions would be:

$ER_i = (20\ kg/hr)(50/100)$
$= 10\ kg/hr$

The stack emissions due to incineration are summarized in Table 37.

4.4.7 Fugitive Emissions

From Table 4, fugitive emissions of all species but VOCs can be assumed to be negligible. Taking the best and worst-case estimates of fugitive losses (4% and 80% of stack emissions), emissions could range from 8×10^{-4} to 1.6×10^{-2} kg/hr. Fugitive particulate matter emissions can be assumed to be zero. This does not include fugitive emissions from the waste feed and ash handling operations.

TABLE 37. STACK EMISSIONS DUE TO INCINERATION

	Uncontrolled Emissions		Controlled Emissions	
Species	Rate (kg/hr)	Total (kg)	Rate (kg/hr)	Total (kg)
VOCs	0.02	2430	0.02	2430
PM	88.5	1.07×10^7	0.54	65,600
Lead	1.42	172,000	0.52	63,100
SO_2	20	2.43×10^6	10	1.21×10^6

4.5 EMISSIONS ESTIMATE FOR SCENARIO THREE

4.5.1 Uncontrolled Emissions

From Equation 13, the hydrocarbon vapor recovery rate per well is:

$$ER_i = (C_i)(Q)$$

From Table 18, an average flow rate is 0.50 m^3/min. From the site description, it is known that the subsurface vapors range from 100,000 to 500 ppm. Assuming a linear distribution and an average molecular weight of 78 (benzene), the average vapor concentration would be 173 g/m^3. [Average concentration = (100,000 + 500)/2 = 50,250 ppm and, for C_6, 1 ppm = 3440 ug/m^3.]

$$\begin{aligned} ER_i &= (173\ g/m^3)(0.50\ m^3/min) \\ &= 86.5\ g/min \\ &= 5.19\ kg/hr \end{aligned}$$

For a site with coarse-textured soil, recovery wells may be located up to 60 m apart. Therefore, each recovery well would cover an area of:

$$\begin{aligned} Area &= \pi r^2 \\ &= (3.14)(60\ m)^2 \\ &= 11{,}300\ m^2 \end{aligned}$$

For a 40-acre site, the number of required wells would be:

$$\begin{aligned} No.\ of\ wells &= (40\ acres)(4097\ m^3/acre)(1/11{,}300\ m^3) \\ &= 14 \end{aligned}$$

Therefore, the overall uncontrolled emissions are:

$$\begin{aligned} ER &= (5.19\ kg/hr)(14) \\ &= 72.7\ kg/hr \end{aligned}$$

4.5.2 Controlled Emissions

From Table 18, controlled emissions for a carbon adsorption system average 75 ppm. Assuming molecular weight = 78, this is roughly 0.258 g/m^3 (75 ppm x 3440 ng/m^3/ppm). Emissions per recovery well are:

$$\begin{aligned} ER &= (0.258\ g/m^3)(0.5\ m^3/min) \\ &= 0.129\ g/min \\ &= 0.0077\ kg/hr \end{aligned}$$

For all 14 wells, this totals to 0.108 kg/hr. If emissions are controlled by sending the vented gas to the incinerator, then emissions can be assumed to be negligible.

4.6 EMISSIONS ESTIMATE FOR SCENARIO FOUR

Assume that the hydrocarbon layer on the ground water can be recovered directly without incurring significant VOC losses. Air stripping of the ground water could be used to clean up the 10 mg/L of benzene contamination. From Table 18, 3500 L/min of water can typically be treated per unit. If one unit is in use, the emissions can be calculated from Equation 8.

$$\begin{aligned} ER &= (10{,}000\ ug/L)(3500\ L/min)(10^{-6})(99.5/100) \\ &= 34.8\ g/min \\ &= 2.09\ kg/hr \end{aligned}$$

From Section 3.4, carbon adsorption control technology (CAS) can be expected to get as low as 50% removal for compounds with benzene's molecular weight. So the controlled emissions would be:

$$\begin{aligned} ER &= (2.09\ kg/hr)(50/100) \\ &= 1.05\ kg/hr \end{aligned}$$

If the air is sent to the incinerator instead of a CAS, then the emissions can be assumed to be negligible.

4.7 SUMMARY AND AMBIENT IMPACT ASSESSMENT

The estimated emission rates for each scenario are summarized in Table 38.

Assessments of emissions are commonly followed by dispersion model assessments of the ambient air quality impacts of these emissions. The selection of a dispersion model and the determination of model inputs are discussed in Volume IV of this series and in other references, and are not discussed here.

Nevertheless, to provide some perspective on the significance of given levels of emissions from remedial actions, a modeling analysis was performed. A range of inputs was used to provide an indication of the range of concentrations that can result from a given rate of emissions. This analysis used the ISCST model. Meteorological data from Albany, NY (1978 data) and from Concord, NH (1981 to 1985 data) were used to represent the Northeastern U.S. Meteorological data from Orlando, FL (1981 to 1985 data) and from Atlanta, GA (1974 to 1979 data) were used to represent the Southeastern U.S. These choices of meteorological data do not provide either the highest or the lowest concentrations that might result from a given emission rate, but they do indicate some of the range of emissions-to-concentration relationships found in the United States.

The dispersion model runs were designed to indicate the downwind concentrations (in ug/m^3) that could result per unit emission rate (1 kg/hr). Results were obtained for both a short-term (1 hour) and a long-term (1 year) average. For both averaging times, the valve below is the highest valve for any time period and for any receptor direction:

TABLE 38. SUMMARY OF EMISSION RATE ESTIMATES

Scenario	VOC (kg/hr) Uncontrolled	VOC (kg/hr) Controlled	Uncontrolled TSP <30 um (kg/hr)	Uncontrolled Inhalable PM < 15 um (kg/hr)	Lead (g/hr)	SO_2 (kg/hr)
1 - Soil Removal						
Excavation	0.07	0.015	6.8	2.0	0.5	--[c]
Transportation	0.63	0	159	15	1.54	--[c]
Dumping	5.1	0.152	0.24	0.16	0.018	--[c]
Grading[a]	5.1	0.152	8.6	4.1	0.64	--[c]
2 - Incineration						
Waste Removal[b]	--	--	--	--	--	--
Waste Feed[b]	--	--	--	--	--	--
Storage	6.84	0.07	0.03	--[c]	--[c]	--[c]
Stack Emissions	0.02	0.02	88.5	--[c]	1420	20
Fugitive Emissions	0.016	--	0	0	0	--[c]
Ash Handling[b]	--	--	--	--	--	--
3 - In-Situ Ventilation	72.7	0.108	--[c]	--[c]	--[c]	--[c]
4 - Ground-Water Stripping	2.09	1.05	--[c]	--[c]	--[c]	--[c]

---

[a] Grading is not expected to increase emissions if performed soon after dumping, so Grading ER = Dumping ER.

[b] Not calculated for this example. Emissions estimation is analogous to soil removal, but VOC emissions would be about 20x higher due to higher VOC content.

[c] Not calculated, assumed to be insignificant.

Downwind Distance	NE U.S. Peak	NE U.S. Average	SE U.S. Peak	SE U.S. Average
10 m	523,000	76,000	508,000	59,900
100 m	9,350	1,490	9,070	893
500 m	587	82	682	48
1 km	295	25	362	14
2 km	157	8	192	5
3 km	109	4	133	2
5 km	69	2	84	1

These values may be multiplied by the emissions estimates to approximate the impact of a remedial action. For example, using the multipliers and the emission rate estimates in Table 38, the impact of the example scenario emissions at various receptors can be evaluated. In Table 38, three values of potential concern due to their large magnitude are:

- uncontrolled TSP from transportation at 159 kg/hr;
- lead from incinerator stack at 1.42 kg/hr; and
- in-situ ventilation at 72.7 kg/hr (uncontrolled) and 0.108 kg/hr (controlled).

Using the multipliers given above, the peak concentrations and annual average concentrations of these contaminants can be calculated for receptors of concern, say at 1 km for a site in the NE U.S. For example:

$$\text{NE Peak Lead at 1 km} = (295\ \text{ug/m}^3\ /\ \text{kg/hr})(1.42\ \text{kg/hr}) = 419\ \text{ug/m}^3$$

Looking at the three values of potential concern, the concentrations at 1 km equals (all values in ug/m^3):

Contaminant	Peak Receptor=1 km	Annual Receptor=1 km	Criterion Short Term	Criterion Long Term
1. Uncontrolled TSP	46,900	2,980	150	50 (for PM-10)
2. Lead	419	35.5	---	1.5
3. Uncontrolled VOC	21,400	1,820	---	---
4. Controlled VOC	31.9	2.7	---	---

Comparison of these impacts to the National Ambient Air Quality Standards for lead and particulate matter indicates that controls for these contaminants may be warranted. No such standard exists for VOC. Instead, individual compound concentrations will generally be calculated for comparison to compound-specific reference doses or for use in estimating cancer risks (similar such calculations may be performed for particulate matter species as well). Also, note that a PM_{15} concentration is being compared to a PM_{10} standard; a more refined analysis should use PM_{10} emissions estimates.

The above calculations provide generalized approximations of ambient impacts of emissions. Analyses for particular sites would generally involve running a dispersion model using locally-representative meteorological data. Such analysis might consider the different locations of multiple sources and the dimensions of the source area. Several other considerations may also affect these analyses and their interpretation. The principal utility of the information in this section is to provide a means of evaluating whether a given remedial action plan leading to a given emissions estimate is likely to have a significant ambient impact.

SECTION 5
INPUT DATA COLLECTION

This section is an introduction to methods for collecting input data for use in the emissions estimation protocol. Data needs and data quality objectives are discussed, followed by descriptions of data collection approaches for assessing emission sources, ambient concentrations, or other data needs. The companion volumes to this manual are excellent sources of information on certain input data collection topics: Volume I (1) for overall air issues, Volume II (2) for developing baseline emission estimates, and Volume IV (3) for ambient air monitoring and dispersion modeling.

5.1 DATA NEEDS/DATA QUALITY OBJECTIVES

Collection of input data for the emissions estimation protocol may be necessary to:

1) Fill an existing data gap;

2) Collect site-specific data to improve an existing emissions estimate; or

3) Measure emissions to verify an emissions estimate.

Data gaps, if present, should be readily identified when executing the protocol. In some cases, an emissions estimate can be improved by collecting input data at the site, or at another similar site, and replacing generic input data with the site-specific data. Verification of an emissions estimate may be warranted for final selection of a remedial option, for atypical sites, or for sites with sensitive receptors in close proximity.

Once the need for input data to the protocol has been identified, the next step is to determine exactly what input parameters are needed, what associated data quality (confidence) is required, and how the data should be collected. The general steps in the process are illustrated in Figure 23.

The two pieces of data most needed for estimating emissions are usually the amount of waste that is present and the average concentration of various pollutants in the waste. An RI/FS usually must be performed at the field site to collect these data. Other types of input data may also be collected from the field site, but a number of alternative information sources may provide the necessary data, including:

- Predictive models;
- Published literature;
- Other Superfund RPMs; and
- Field data from other hazardous waste sites.

Other sources should be considered before committing to the time and expense of a field study.

If field data are required, sampling and analytical methods must be selected and a quality assurance/quality control program developed. Sampling methods for determining air quality are discussed in Section 5.2. The analytical methods and QA/QC program needs will depend directly on the data quality needs. This dependence is summarized in Table 39. Data quality can be indicated by the PARCC (precision, accuracy, representativeness, completeness, and comparability) parameters. A complete description of data quality and QA/QC is beyond the scope of this manual. The EPA has published guidance on these topics and they should be referred to for further information (56,57,58).

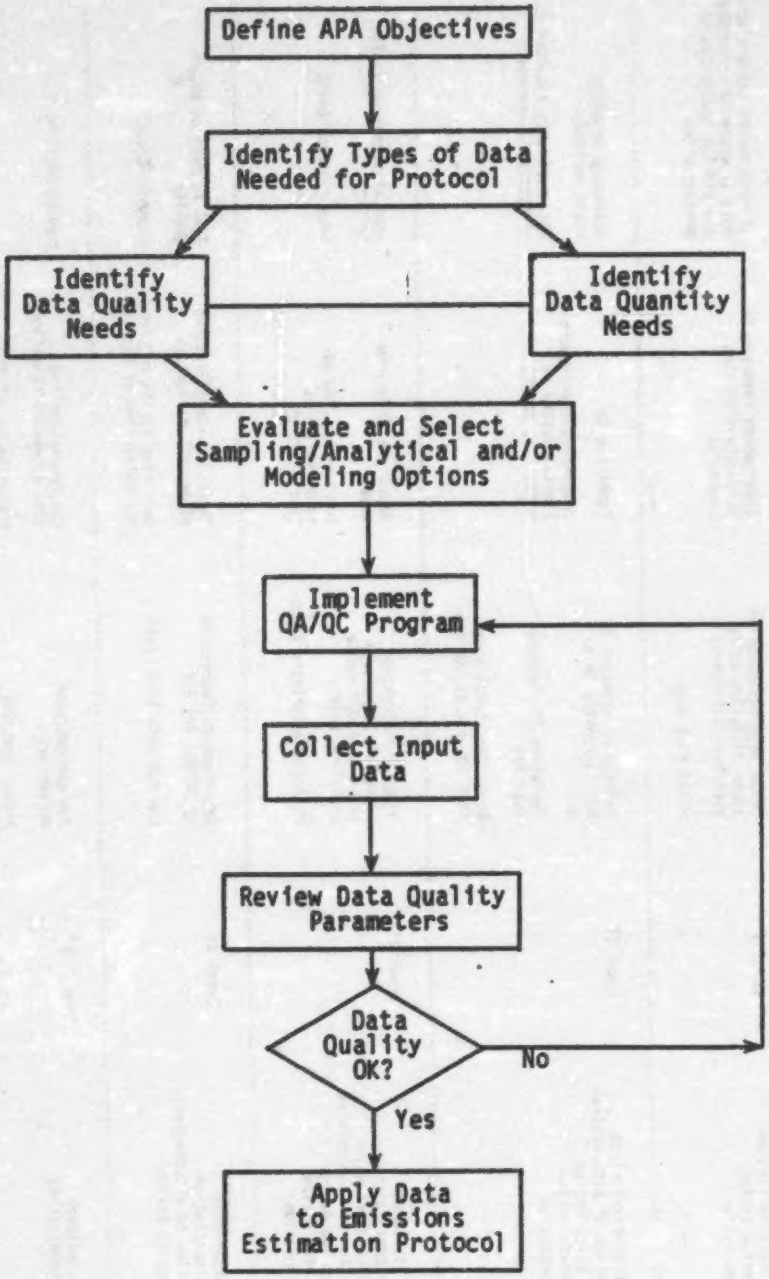

Define APA Objectives
Identify Types of Data Needed for Protocol
Identify Data Quality Needs
Identify Data Quantity Needs
Evaluate and Select Sampling/Analytical and/or Modeling Options
Implement QA/QC Program
Collect Input Data
Review Data Quality Parameters
Data Quality OK?
No
Yes
Apply Data to Emissions Estimation Protocol

Figure 23. Flowchart for input data collection.

TABLE 39. SUMMARY OF ANALYTICAL LEVELS APPROPRIATE TO DATA USES

Data Uses	Analytical Level	Type of Analysis	Limitations	Data Quality
Site Characterization Monitoring during Implementation	Level I	Total organic/inorganic vapor detection using portable instruments Field test kits	Instruments response to naturally-occurring compounds	If instruments calibrated and data interpreted correctly, can provide indication of contamination
Site Characterization Evaluation of Alternatives Engineering Design Monitoring during Implementation	Level II	Variety of organics by GC; inorganics by AA; XRF Tentative ID; Analyte-specific Detection limits vary from low ppm to low ppb	Tentative ID Techniques/instruments limited mostly to volatiles, metals	Dependent on QA/QC steps employed Data typically reported in concentration ranges
Risk Assessment PRP Determination Site Characterization Evaluation of Alternatives Engineering Design Monitoring during Implementation	Level III	Organics/inorganics Using EPA procedures other than CLP can be analyte-specific RCRA characteristic tests	Tentative ID in some cases Can provide data of same quality as Levels IV, MS	Similar detection limits to CLP Less rigorous QA/QC
Risk assessment PRP Determination Evaluation of Alternatives Engineering Design	Level IV	HSL organics/inorganics by GC/MS; AA; ICP Low ppb Detection Limit	Tentative identification of non-HSL parameters Some time may be required for validation of packages	Goal is data of known quality Rigorous QA/QC
Risk Assessment PRP Determination	Level V	Non-conventional parameters Method-specific detection limits Modification of existing methods Appendix 8 parameters	May require method development/modification Mechanism to obtain services requires special lead time	Method-specific

Source: Reference 56.

5.2 DATA COLLECTION APPROACHES

This section introduces approaches for collecting data to assess air quality and air quality impacts. This subject is covered in more detail in Volume II (2). Emission source assessments, ambient concentration assessments, and other data needs are included. The emphasis is on sampling methods and modeling of contaminants in the atmosphere. Analytical methods for measuring contaminant levels in gas, liquid, and solid samples have been standardized and published elsewhere; this topic is therefore only briefly discussed under other data needs.

5.2.1 Emission Source Assessments

Assessment of an emission source typically involves measuring or modeling an emission or production rate for each contaminant of interest. Emission rate information for hazardous waste sites can be used for exposure assessment, assessing air quality impacts under various meteorological conditions, and developing suitable control strategies. Both direct and indirect measurement techniques are available. The direct measurement techniques are usually simpler, more accurate, and less expensive; however, the indirect measurement techniques may be the only suitable approach for certain applications (e.g., large heterogeneous area sources).

Direct measurement techniques include vent sampling (59) of ducts at point sources, and the enclosure (flux chamber) (60-67) approach for sampling area sources. Indirect measurement techniques include mass balance, transect (68,69), and concentration profile (40,70,71) techniques.

A vast amount of research has been conducted to develop, validate, and evaluate predictive models for hazardous waste sources, especially with respect to VO emissions from area sources and transfer operations. The best source of information on this topic is EPA's Office of Air Quality Planning and Standards (OAQPS). OAQPS has published an evaluation of mathematical modeling techniques to predict volatile air emissions release from various sources (72). This work has recently been revised (73) and the new report includes models on diskette for use on a microcomputer. Guidance for estimating particulate matter emissions was published by OAQPS in 1988. The computer-compatible air emission models, referred to as CHEMDAT 6 models, cover the following sources:

- Surface impoundments (non-aerated), which for modeling purposes include quiescent impounds and open-top tanks:
  - -- Disposal impoundments,
  - -- Storage impoundments;
- Land treatment:
  - -- Soil emissions subsequent to waste tilling,
  - -- Oil layer on soil (prior to tilling);
- Closed landfills;
- Open landfills;
- Wastepiles;
- Oil film on a liquid surface;
- Diffused air systems; and
- Mechanically aerated systems.

The Superfund Exposure Assessment Manual (74) and the companion volumes to this manual (2,3) also contain guidance on selecting and using emission models. Users should consult Reference 73 or the other citations for more information.

Predictive models for emissions from incinerators, air strippers, and in-situ venting systems are not currently available.

5.2.2 Ambient Concentration Assessments

This manual has focused on the estimation of emissions from remedial actions for cleaning up abandoned hazardous waste sites. Commonly, the resulting emissions estimate is then used in an atmospheric dispersion modeling analysis to estimate ambient concentrations of the emitted pollutants. These ambient concentrations may then be evaluated using available health data to determine the acceptability of the concentrations and the need for emissions controls.

An alternative method often used for assessing ambient concentrations is to measure the concentrations with monitoring equipment. The monitoring alternative has several advantages and several disadvantages relative to the emissions estimation/dispersion analysis alternative. The greatest advantage of the monitoring alternative is that under some circumstances, viz. when pollutant concentrations reflect representative circumstances (especially representative meteorology), the measurements have greater reliability. This advantage of relative reliability is particularly pronounced for some types of cases such as soils handling where the emissions estimates are quite uncertain and where even the existence of emissions of particular pollutants may be in doubt.

The greatest advantage of the emissions estimation/dispersion analysis alternative is the ability to predict impacts. Indeed, monitoring is simply not an alternative for assessing concentrations before the emissions have begun. Thus for example, in feasibility studies the emissions estimation/dispersion analysis approach is the only feasible means of predicting the air quality impacts of various remedial alternatives being considered.

Ambient monitoring and emissions estimation/dispersion analysis have numerous other advantages and disadvantages. Ambient monitoring is clearly advantageous for activities for which emissions estimation procedures are unavailable. On the other hand, the emissions estimation/dispersion analysis approach can provide more trustworthy results when background concentrations are high, when concentrations are too low to measure, or when the monitoring study is too short for measurements to provide a reliable, representative assessment of remedial action impacts. This advantage of emissions estimation/dispersion analysis is particularly important in the frequent situation where monitoring detection limits are much higher than health-based criteria. The emissions estimation/dispersion analysis approach has an added advantage, for sites with multiple activities or multiple operable units, of being readily able to distinguish separate impacts of individual activities or operable units. Furthermore, the emissions estimation/dispersion analysis is a much less expensive alternative.

A more complete discussion of monitoring and of dispersion analysis is provided elsewhere. Two companion volumes to this manual specifically address procedures and purposes of monitoring and dispersion analysis in addressing air impacts of abandoned hazardous waste sites (2,3). Also of interest are the overviews prepared for RCRA (75). Further references are available that discuss monitoring and dispersion modeling in more detail, such as guidance on developing data quality objectives (56), guidance on network design (76), guidance on particular monitoring methods (e.g., 77 and 78), and the air quality modeling guidelines (79).

This manual has sought to compile available information to assist in estimating emissions from various types of NPL site cleanup activities. This concluding section has attempted to put such emissions estimation in the broader perspective of assessing impacts of these emissions. A common philosophy is that "If it can't be measured, it is not there". This philosophy ignores the important role that emissions estimation, generally followed by dispersion analysis, can play when monitoring is less reliable, less practical, or even impossible. This philosophy ignores the value of emissions estimation and dispersion analysis in planning and in evaluation of potential remedial actions, where monitoring is not a meaningful alternative. It is hoped that this manual will provide the information and procedures necessary to make this planning and evaluation of air quality impacts of potential remedial actions a more reliable and more commonplace element of the process for addressing abandoned hazardous waste sites.

SECTION 6
REFERENCES

NOTE: Many of these references are synopsized in Appendix A.

1. NUS Corporation. Procedures for Conducting Air Pathway Analyses for Superfund Applications - Volume I, Application of Air Pathway Analyses for Superfund Activities. EPA Draft Manual, December 1988.

2. Radian Corporation. Estimation of Baseline Air Emissions at Superfund Sites. EPA Interim Final Manual, January 1989.

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APPENDIX A

ANNOTATED BIBLIOGRAPHY

BIBLIOGRAPHY

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   Good reference explaining tests of a new control technology for VOC emissions from landfills-foam. Paper gives some useful data showing effects of varying the percent of stabilizing chemical, percent of foaming chemical, application weight, and expansion ratio. No cost information, nor guidance as to when to select the method.

2. Alm, R.R., K.A. Olson, and E.A. Reiner. Stabilized Foam: A New Technology for Vapor Suppression of Hazardous Materials. Presented at International Congress on Hazardous Materials Management, Chattanooga, TN, June 1987.

   Focuses on foam as a control technology for accidental spills and waste sties. In general, the less polar or water-soluble the organic, the better the vapor suppression by the stabilized foam. Environmental concerns of using the foam (toxicity, leachability, biodegradation, photochemical degradation, etc.) are addressed.

3. Alm, R.R., K.A. Olson, and R.C. Peterson. Using Foam to Maintain Air Quality During Remediation of Hazardous Waste Sites. Presented at the Air Pollution Control Association's 80th Annual Meeting and Exhibition, New York, NY. June 1987.

   Describes field tests where foam was employed and successfully mitigated the air pollution hazard. A burning landfill and a petroleum waste site are discussed. Some minimal cost information is presented.

4. Arthur D. Little, Inc. Evaluation of Emission Controls for Hazardous Waste Treatment, Storage, and Disposal Facilities. PB85 163657. Prepared for the U.S. Environmental Protection Agency, OAQPS, Research Triangle Park, NC. November 1984.

   This document covers volatile emissions from hazardous waste handling via surface impoundments, treatment and storage tanks, landfills, and landfarms. It gives an estimate of each category's share of total emissions. Depending on where it is applied, it breaks controls into four classes: pretreatment, design and operating practices, in-situ controls, and post-treatment. It presents emission equations for each category and lists control techniques for all classes and categories. It also estimates the control efficiency for several techniques.

5. Barnard, W.R., D.F. Gatz, G.J.Stensland. Chemical Characterization of Aerosols Emitted from Vehicle Traffic on Unpaved Roads. Presented at the 80th Annual Meeting of the Air Pollution Control Association, New York, NY. June 11-26, 1987.

   Depletion of some elements in fine and coarse aerosol fraction from unpaved roads occurs relative to the road source material (<53 um). This study showed that Si had the largest depletion of the following elements: Ti, Si, Na, V, K, Cl, Mn, and Ca. Depletion was found to be dependent both on particulate size fraction and road surface type.

   Sampling of the road surface material and subsequent determination of this elemental chemistry may not adequately represent the ultimate chemistry of the aerosol derived from this source.

6. Barnard, W.R., D.F. Gatz, and G.J. Stensland. Elemental Chemistry of Unpaved Road Surface Materials. Presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN. June 22-27, 1986.

   The study described in this paper was performed to determine if an unpaved road surface could be characterized as to its elemental contact, particularly minerals such as Ca and K. Impetus to perform the study came from unexplained limestone components in the fugitive dust in urban areas. The component was attributed to "soil" or "entrained" dust, but the composition of the "soil" component is not well known. This paper does not appear to contain any information useful for assessing air emissions from NPL sites.

7. Barnard, W.R., G.J. Stensland, and D.F. Gatz. Alkaline Materials Flux from Unpaved Roads: Source Strength, Chemistry, and Potential for Acid Rain neutralization. Water, Air, and Soil Pollution, Volume 30, pp. 285-293, 1986.

   This paper contains no information useful for assessing air emissions from NPL sites.

8. Barnard, W.R., G.J. Stensland, and D.F. Gatz. Development of Alkaline Emissiolux Estimates from Unpaved Roads: Problems and Data Needs for Modeling Potential Acid Rain Neutralization. Presented at the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, MN. June 22-27, 1986.

   Describes study to predict alkaline emissions (Ca, Mg, K, Na) from travel on unpaved roads. Discusses potential probems and inconsistencies with the two methods (dispersion modeling and mass balance approaches) used to develop the emission factor equations.

Potential problems mentioned may be insightful to this project, but no new emission factor equations are presented. Report uses AP-42 unpaved road equation and introduces factors to account for surface area of state, elemental abundance in the state, based on U. S. Geological Survey data, etc.

9. Barnard, W. R., G. J. Stensland, and D. F. Gatz. Evaluation of Potential Improvements in the Estimation of Unpaved Road Fugitive Emission Inventories. Presented at the 80th Annual Meeting of the Air Pollution Control Association, New York, NY. June 21-26, 1987.

The paper addresses fugitive particulate inventories on a statewide level. Three parameters are introduced to the AP-42 equation for unpaved road fugitive emissions in an attempt to increase the accuracy of the state emission inventory. These corrections pertain only to inventory on the state level and are not applicable to individual hazardous waste sites.

10. Basden, L. S. Characterization of Fugitive Particulate Emissions from Industrial Sites. Proceedings--Fifth Symposium on the Transfer and Utilization of Particulate Control Technology, Volume 4, Kansas City, MO. August 1984. F. A. Ayer, Compiler, Prepared by Research Triangle Institute, Research Triangle Park, NC. February 1986.

Discusses accuracy and applicability of emissions data obtained by hi-volume samplers and deposition gauges (i.e., long sampling period instruments). Doubts the accuracy of emissions estimates that are "back-calculated" by modeling. Introduces current work with portable cascade impactor and related instruments that use shorter sampling times to determine more site-specific emission rates as opposed to overall average values from long sampling periods. Lists emission factors from long-term techniques for haul trucks, blasting, truck loading and dumping, drilling, top soil removal, and draglines.

11. Bonner, T. A., C. L. Cornett, B. O. Desai, J. M. Fullenkamp, and T. W. Hughes. Engineering Handbook for Hazardous Waste Incineration. MRC-DA-1090; EPA/SW-889. Prepared by Monsanto Research Corp. for U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. September 1981.

This is an engineering design handbook which provides suggested minimums and/or acceptable ranges for incinerator performance parameters. Discusses current practices; waste characterization; and incineration facility design, operation, monitoring, and cost estimating. Results from a number of trial burns are summarized.

12. Brna, T. G. and C. B. Sedman. Waste Incineration and Emission Control Technologies. EPA/600/D-87/147. U.S. Environmental Protection Agency, AEERL, Research Triangle Park, NC. May 1987.

Discusses various in-furnace and post-combustion technologies for controlling pollutants such as POHCs, acid gases, trace heavy metals, and particulates. Tabulated control efficiency data are provided for acid gas control systems, spray dryer control of dioxins and furans, and heavy metal control systems.

13. Calvert, S. and H. M. Englund, editors, Handbook of Air Pollution Technology. John Wiley and Sons, New York, NY. 1984.

One section on control of fugitive emissions. Not very detailed in areas of already viable technology (mostly wet spray methods). More detail for "new concepts" such as spray charging and trapping, charged fog spray, road carpets, improved street sweepers, and windscreens. Some limited data on costs, concentration reduction.

14. Caravanos, J. and T. T. Shen. The Effect of Wind Speed on the Emission Rates of Volatile Chemicals from Open Hazardous Waste Dump Sites. Air Monitoring, p. 68, 1984.

Equation relates emissions from the top layer of soil. Laboratory data based on benzene, carbon tetrachloride, and trichloroethylene for clay, sand, and organic topsoil. Once the top layer of chemically contaminated soil evaporates, other equations can be used for subsurface emission.

15. Cheremisinoff, P. N. Special Report: Hazardous Materials and Sludge Incineration. Pollution Engineering, Volume 18, Number 12, pp. 32-38. December 1986.

General overview of hazardous waste incineration. Incinerator types, waste and fuel characteristics, and new thermal destruction technologies are discussed.

16. Cowherd, C. Jr. Measurement of Particulate Emissions From Hazardous Waste Disposal Sites. Paper 85-73. Proceedings--78th APCA. Annual Meeting, Detroit, MI. Air Pollution Control Association, Pittsburgh, PA. June 1985.

This paper discusses methods of measuring fugitive emissions from hazardous waste sites and open waste piles. Methods include wind erosion measurement by wind tunnel tests and emissions from mechanical entrainment processes by upwind/downwind sampling. Particle sizing by high-volume cyclone/cascade impactor combinations is also discussed. More detail is provided here than in the User's Guide for Unpaved Road Emissions.

17. Cowherd, C. Jr. and J. S. Kinsey. Identification, Assessment, and Control of Fugitive Particulate Emissions. Prepared for the U. S. Environmental Protection Agency, AEERL, Research Triangle Park, NC. August 1986.

Does not contain any emission factors or equations—just methods and important steps for preparing emissions inventories. Primary purpose of document is to identify control alternatives and estimate control system performance. Contains efficiency data tables.

18. Davis, E. A., J. H. Meyer, J. A. Kagan, and V. T. Freeman. Fugitive Dust Emissions from the Proposed Vienna Unit No. 9. Prepared for Maryland Power Plant Siting Program. PB81-190175. Johns Hopkins University. Laurel, MD. February 1981.

History of development of emission factor equations from storage piles, and how different dependent variables were added. Applied best available emission equations to a specific site (coal-burning utility). Control methods are documented and efficiencies are estimated. Also contains description of model simulation used and results of simulation.

19. Dellinger, B., et al. Determination of the Thermal Decomposition Properties of 20 Selected Hazardous Organic Compounds. U.S. EPA, EPA-600/2-84-138. August 1984.

Reports the thermal decomposition profiles and kinetic data for 20 hazardous organic compounds. These data were generated in the laboratory and extrapolated to determine the temperature required to achieve 99.99% destruction. The analytical results are discussed and explained in terms of possible chemical reactions and mechanisms for destruction of POHCs. Parameters which potentially affect incineration efficiency are discussed and four methods of predicting relative incinerability of compounds are reviewed.

20. Dellinger, B., et al. Predicting Emissions from the Thermal Processing of Hazardous Wastes. Hazardous Wastes and Hazardous Materials, Vol. 3, No. 3, pp. 293-307. 1986.

Evaluates a number of "incinerability" ranking methods by comparing each method's predicted results to the observed incinerability for ten hazardous waste thermal destruction systems. The only method which successfully predicted the field results is based on laboratory determined thermal stability for hazardous waste mixtures under oxygen deficient conditions. Another finding of this study is that formation of POHCs in the incineration process significantly affects DRE for all but the most difficult to form POHCs.

21. Englehart, P. J., and C. Cowherd, Jr. Assessment of Fugitive Particulate Emissions From Hazardous Waste Treatment, Storage, and Disposal Facilities: An Overview of Survey/Sampling Efforts with Preliminary Analytical Results. Proceedings--79th APCA Annual Meeting. Vol. 1. Air Pollution Control Association, Pittsburgh, PA. 1986.

A condensed version of a separate report prepared for EPA, May 1986. Program is not based on actual air sampling, but assumes that existing model (AP-42) can be used in combination with physical/chemical properties of surface material samples from hazardous waste treatment, disposal, and storage facilities (TSDFs). Samples were analyzed for the following parameters: percent silt by weight, fraction by weight of silt that has a physical diameter less than 20 um, percent moisture by weight, and concentrations of many metals, organics, and pesticides/PCBs on the Hazardous Substances List. Metal concentrations were enriched in the silt, and in the <20 um silt particles. RCRA metal concentrations are highest for landfill surface samples and lowest for landtreatment units.

22. Frederick, E. R., editor. A Specialty Conference on Fugitive Dust Issues in the Coal Use Cycle. Pittsburgh, PA. Air Pollution Control Association, April 11-13, 1983.

Two articles on measuring/modeling fugitive emissions; most of the useful articles contain information on control technologies: dust suppressants and weather dependency, micron-sized water particle spray, windscreens, microfoam.

23. Gravitz, N. Derivation and Implementation of Air Criteria during Hazardous Waste Site Cleanups. Journal of the Air Pollution Control Association, Volume 35, Number 7. July 1985.

Gives brief regulatory overview and extensive discussion of modeling. Covers fence-line criteria and community exposure standards. Does not address actual emissions.

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Provides guidelines for designing hazardous waste incinerators. Waste feed control, combustion control, afterburner operation, emission control, and effluent gas monitoring are discussed.

25. Harrington, E. S., G. A. Holton, and F. R. O'Donnell. Initial Emission Assessment of Hazardous-Waste-Incineration Facilities. CONF-820418-20. Prepared by Oak Ridge National Lab for Department of Energy, Washington, D.C. 1982.

Discusses the results of an EPA study to quantify the emissions from various operations at a typical hazardous waste incinerator facility. Related work is discussed in Holton 1984a, Holton 1984b, and Travis 1984.

26. Hill, R. D. Stabilization/Solidification of Hazardous Waste. EPA/600/D-86/028. Environmental Protection Agency, Hazardous Waste Engineering Research Lab, Cincinnati, OH. January 1986.

Discusses such techniques as sorption, the lime-fly ash Pozzolan process, Pozzolan-Portland cement processes, thermoplastic microencapsulation, macroencapsulation, and other techniques. Gives some suggestions for determining which processes may be unsafe for certain types of waste. Suggested physical and chemical analyses to be performed to characterize the waste are also included.

27. Holton, G. A., C. C. Travis, E. L. Etnier, and F. R. O'Donnell. Inhalation Pathway Risk Assessment of Hazardous Waste Incineration Facilities. Proceedings--77th APCA Annual Meeting, Volume 6, San Francisco, CA. Air Pollution Control Association, Pittsburgh, PA. 1984a.

Atmospheric transport modeling is used to estimate exposure risk to two hypothetical incineration units. Fugitive emissions from handling operations (valves, tanks, etc.) may be an important contributor to total emissions, especially for small incinerators.

28. Holton, G. A., and C. C. Travis. Methodology for Predicting Fugitive Emissions for Incinerator Facilities. Environmental Progress Volume 3, Number 2. Oak Ridge National Lab, Health & Safety Research Division, Oak Ridge, TN. May 1984b.

Studies of stack vs. fugitive emissions have shown that atmospheric pollutant concentrations and population exposures at close-in locations are more affected by fugitive releases. This phenomena is attributed to the low temperature and ground level emission characteristics of fugitives. There is wide variability in fugitive emissions which includes those caused by leaky pump fittings, sampling connections, flanges, storage tanks, and other non-stack equipment. Error analysis and Monte Carlo modeling was used to develop emissions predictions methods. Ten equations and three parameter value tables are provided for emission calculations.

29. Hwang, S. T. Measuring Rates of Volatile Emissions from Non-Point Source Hazardous Waste Facilities. Proceedings--Annual Meeting - Air Pollution Control Association, Volume 75 Number 4. U.S. Environmental Protection Agency, Washington, DC. 1982.

This paper develops the mathematics of a new method of measuring toxic emissions from area sources. The method requires concentrations and velocities simultaneously measured at different heights above the sources. It is similar to the "Concentration Profile Technique," but requires fewer data points. The method is preliminary, and a comparison with the Concentration Profile Technique was not available at the time the paper was presented. If successful, the method could also be applied to landfills and landtreatment facilities.

30. Hwang, S. T. Toxic Emissions from Land Disposal Facilities. Environmental Progress Volume 1, Number (1), p. 46. February 1982.

Mass transfer equations are given which allow estimation of toxic emissions from landfills and landtreatment facilities. Data needed to apply these equations include soil mass transfer coefficients, porosity and tortuosity of cover material, air-phase mass transfer coefficients, partial pressure of component i in equilibrium with the waste, molecular weight of i, temperature, and landfill area. Not all the variables in the equations are well defined.

31. Johnson, L. D. Detecting Waste Combustion Emissions: Several Advanced Methods are Useful for Sampling Air Contaminants from Hazardous Waste Incinerator Stacks. Report No. EPA/600/J-86/010. Published in Environmental Science and Technology, Volume 20, Number 3. Environmental Protection Agency, Research Triangle Park, NC. 1986.

Discusses sampling and analytical methods for air contaminants in hazardous waste incinerator stacks.

32. King, J., compiler, Second Symposium on Fugitive Emissions: Measurement and Control. (May 1977, Houston, Texas). EPA-600/7-77-148. U. S. Environmental Protection Agency, IERL, Research Triangle Park, NC. December 1977.

Three papers on measurement and monitoring. The first covers exposure profiling technique for measuring fugitive particulate emissions. The second gives preliminary findings of a grab-sampling effort to monitor fugitive dust emissions at a large coal cleaning plant. The monitoring was performed prior to operation of the plant. The third article summarizes the results of a study to determine the size of quench tower particulate emissions and sampling methods. The other articles do not appear to contain any information useful to the program.

33. Lee, C. C., G. L. Huffman, and D. A. Oberacker. Hazardous/Toxic Waste Incineration. Journal of the Air Pollution Control Association, Volume 36, Number 8. EPA, Cincinnati, OH. August 1986.

General overview of waste incineration technology. Discusses advantages and disadvantages of liquid injection, rotary kiln, and hearth incinerators. Air pollution control and monitoring requirements are also discussed.

34. Oppelt, E. T. Hazardous Waste Destruction. Environmental Protection Agency Hazardous Waste Engineering Research Lab, Cincinnati, OH. Report No. EPA/600/J-86/107. Published in Environmental Science and Technology, Volume 20, Number 4, 1986a.

Profiles current state of hazardous waste thermal destruction technology in the U.S., including facilities and typical wastes. EPA performance test results presented in (Oppelt 1986c) are also presented here. Also discussed are: incinerability ranking methods, PIC emissions, and current and future thermal destruction capacity.

35. Oppelt, E. T. Incineration of Hazardous Waste, A Critical Review. Journal of the Air Pollution Control Association, Vol. 37, No. 5, May 1987.

Thorough overview of the current state of knowledge in the field of hazardous waste incineration. Covers regulatory issues pertinent to waste incineration, current incineration practices, process performance measurement, emissions from hazardous waste incineration, predicting incinerator performance, environmental and public health implications, and remaining issues and research needs.

36. Oppelt, E. T. Performance Assessment of Incinerators and High Temperature Industrial Processes Disposing Hazardous Waste in the United States. Environmental Protection Agency Hazardous Waste Engineering Research Lab, Cincinnati, OH. Report No. EPA/600/D-86/133. July 1986b.

Discusses EPA performance test results which indicate that incinerators and many high temperature industrial processes are capable of achieving existing performance and emissions standards while burning organic hazardous wastes.

37. Oppelt, E. T. Thermal Destruction of Hazardous Waste. Environmental Protection Agency Hazardous Waste Engineering Research Lab, Cincinnati, OH. Report No. EPA/600/D-86/007. January 1986c.

Profiles thermal destruction technology, current practice in the U.S., design considerations, and summarizes the results of the EPA performance assessments of hazardous waste thermal destruction facilities in the U.S.

38. Orlemann, J. A. and G. A. Jutze. Fugitive Dust Control Technology. Book - Available from Noyes Publications, Mill Road at Grand Avenue, Park Ridge, NJ. 07656. 1983.

A compilation of emission factors and equations for several industries. A section on general fugitive dust emission sources includes equations for unpaved roads, storage piles (load-in, erosion, activity, load-out), truck dumping, and area stripping by equipment type: scraper or dragline.

39. PEDCo Environmental, Inc. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions. EPA-450/3-77-010, U. S. Environmental Protection Agency, OAQPS, Research Triangle Park, NC. March 1977.

A source of emission factors, but few equations—studies were performed on fugitive emissions from several industries, including smelting industries, grain transportation and storage, Portland cement manufacturing, lime manufacturing, and also common dust sources, including transfer, loading, roads, storage piles, and waste sites. Description and costs of available control measures are given.

40. Phillips, K., and J. Malek. Dredging as a Remedial Method for a Superfund Site. Dredging and Dredged Material Disposal, Proceedings of Conference held in Clearwater Beach, FL. November 14-16, 1984. Prepared by U.S. Army Corps of Engineers, Environmental Resources Section, Seattle, WA.

Discusses dredging a bay at Tacoma, Washington. One problem encountered was disposal of the contaminated material after dredging, and a few alternatives were discussed. While loss of volatiles is usually not a problem in dredging, mechanical dredging is preferred if this is a problem. Hydraulic dredging is better for removal of sediment-bound contaminants.

41. Rosbury, K. D. and S. C. James. Control of Fugitive Dust Emissions at Hazardous Waste Cleanup Sites. PEI Assoc., Inc. Eleventh Annual Research Symposium on Land Disposal of Hazardous Waste 8525035, Cincinnati, OH. 1985.

Control efficiencies of windscreens, water sprays, and surfactant spray on wind erosion and fugitive particulates from activity. Both storage piles and land plots were tested. Windscreen/storage pile emission data limited because sampling equipment only picked up particles smaller than 10 um. Active site cleanup—control efficiencies for front-end loader travel/scraping and dumping. Surfactants found to be most effective control technologies.

42. Rosbury, K. D., W. Kemner. Quantification of Roadway Fugitive Dust at a Large Midwestern Steel Mill. Proceedings—Fifth Symposium on the Transfer and Utilization of Particulate Control Technology, Volume 4, Kansas City, MO. August 1984. F. A. Ayer, Compiler, Prepared by Research Triangle Institute, Research Triangle Park, NC. February 1986.

This paper quantified roadway emissions in a major Midwestern steel mill which has over 80 miles of road. Data was collected in a field survey, and emission factor equations were developed for unpaved and paved roads. The emissions were functions of parameters such as road silt content, speed, vehicle weight, and rainfall.

43. Shen, T. T. Hazardous Waste Incineration: Emissions and Their Control. Pollution Engineering, Volume 18, Number 7, July 1986.

Discusses the importance of physical and chemical characterization of waste with respect to incineration system design. Emission control techniques are also reviewed.

44. Shen, T. T. and G. H. Sewell. Air Pollution Problems of Uncontrolled Hazardous Waste Sites. Civil Engineering for Practicing and Design Engineers. Volume 3, Number 3, pp. 241-252. 1984.

Identifies fugitive dust emissions and waste volatilization as important mechanisms for transfer of hazardous materials to the atmosphere. Gives predictive equations for unpaved roads, buried wastes, dump sites with no covering material, and industrial lagoons. Also includes control techniques for unpaved roads, as well as discussions of various regulatory requirements.

45. Springer, C., K. T. Valsaraj, and L. J. Thibodeaux. In-Situ Methods to Control Emissions from Surface Impoundments and Landfills. EPA/600/S2-85/124. U. S. Environmental Protection Agency, HWERL, Cincinnati, OH. July 1986.

Most of the control methods examined were employed over surface impoundments (i.e., ponds); however, synthetic membranes over landfills were tested. A 20-mil PVC membrane showed a high permeability for a number of volatile organic vapors. Typical results showed it to be the equivalent of only a few inches of porous soil covering. Simple laboratory tests are available to measure permeability of (other) specific membranes to specific vapors.

46. Travis, C. C., E. L. Etnier, G. A. Holton, F. R. O'Donnell, D. M. Hetrick. Inhalation Pathway Risk Assessment of Hazardous Waste Incineration Facilities. Oak Ridge National Lab, TN. Report No. ORNL/TM-9096. October 1984.

Using two hypothetical incineration facility designs of three sizes each, burning three different generic wastes, the relative importance of plant design and waste physicochemical variables on human inhalation exposure and health risk was evaluated. Air concentrations were estimated for both stack and fugitive emissions. Stack emissions were calculated using assumed values for DRE; however, fugitives were calculated using equations which relate incinerator facility operation and configuration to fugitive emissions.

47. Trenholm, A., R. Hathaway, and D. Oberacker. Products of Incomplete Combustion from Hazardous Waste Incinerators: Proceedings of the Tenth Annual Research Symposium held at Ft. Mitchell, Kentucky on April 3-5, 1984. Report No. EPA-600/9-84-022. September 1984.

Three mechanisms are proposed to explain the presence of POHCs in the stack gas when the same POHCs are at less than 100 ug/g concentrations in the waste feed. These mechanism are:

- Difficult to burn POHCs present in feed at concentrations <100 ug/g (Relative Contribution - 0-68%).
- Compounds introduced from source other than waste feed (Relative Contribution - 0-14%).
  - a) Trihalomethanes from the scrubbing liquid.
  - b) POHCs from ambient air inleakage (0-50% of total stack air flow).
  - c) POHCS from the auxiliary fuel.
- Actual products of incomplete combustion or from complex side reactions (Relative Contribution 32-100%). Common PICs include benzene and chlorinated and non-chlorinated benzene derivatives. PIC output rate rarely exceeds 0.01% of POHC input (i.e., 99.99 DRE is achieved).

48. Trenholm, A., and D. Oberacker. Summary of Testing Program at Hazardous Waste Incinerators. Proceedings—Annual Solid Waste Research Symposium, Cincinnati, OH. Report No. CONF-8504122. Published by U.S. Environmental Protection Agency, Cincinnati, OH. 1985.

Summarizes the results of tests conducted at eight full-scale hazardous waste incineration facilities. Measurements were taken on various pollutant emissions including EPA Appendix VII compounds, particulates, HCl, CO, and total hydrocarbons. Data analysis allowed evaluation of DRE, PIC formation, pollutant emission levels, pollution control system performance, and relationships between operating conditions and DRE. The results are summarized as follows:

POHCs - Three types of relationships between DRE and operating parameters are addressed: 1) The waste feed concentration correlated strongly with DRE. DRE increases with increasing concentration. Linear regression techniques provided the following relationships for penetration (1-DRE) versus waste feed concentration (WFC):

Volatile Compounds: $\text{Log}(1-\text{DRE}) = -0.79(\text{Log}(\text{WFC}))-1.585$
Semivolatile Compounds: $\text{Log}(1-\text{DRE}) = -0.81(\text{Log}(\text{WFC}))-1.49$

2) There is no significant correlation between DRE and the heat of combustion of the POHCs. 3) Of the operational parameters such as combustion chamber temperature, residence time, and stack gas oxygen content, the only operating variable strongly related to DRE is the combustion chamber temperature. Also, carbon monoxide and total hydrocarbon concentrations in the stack gas do not appear to be good predictors of POHC concentrations.

PICs - PICs are compounds found in the stack gases, but not detected in the waste feed stream. Three possible explanations for these compounds are presented: 1) The PICs are present in the feed stream in concentrations below detection limits, and experience little or no destruction. The trend of decreasing DRE with decreasing waste feed concentration supports this and could explain the presence of many of the PICs detected. 2) Some PICs are introduced from non-waste feed sources. Chloroform, for example, has been shown to be introduced to the system from the scrubber makeup water. Fuel oil can also be a source for PICs. 3) Compounds which are actually created in the combustion process. The presence of simple stable compounds such as chlorinated methanes, ethanes, and benzene compounds in most stacks supports this hypothesis.

HCl - Most hazardous waste incinerators which require add-on HCl control equipment use some type of countercurrent wet scrubber for HCl removal. Of the facilities tested, those equipped with packed towers achieved 99% removal and emitted less than 1 kg/hour of HCl. One unit equipped with a venturi scrubber and a mist eliminator achieved a 97-98% removal and emitted 0.3 kg/hour.

Particulates - Complying with the particulate emission standard of 180 mg/Nm^3 (corrected to 7% O_2) is difficult. Facilities firing waste with greater than 0.5% ash content will have difficulty. Contents of 0.2 to 0.5% may still create emissions problems, but contents of less than 0.1% should not cause failure to meet the standards.

49. U. S. Environmental Protection Agency. AP-42: Compilation of Air Pollutant Emission Factors, Fourth Edition. U. S. Environmental Protection Agency, OAQPS, Research Triangle Park, NC. September 1985.

Reviewed Section 8.19.1 on sand and gravel processing, Section 8.19.2 on crushed stone operations, Section 8.2.4 on western surface coal mining, and Section 11.2 on fugitive dust sources. Sections contained several emission factors and emission equations. In general, a predictive equation should include some measure of source activity or expended energy (e.g., feed rate, number of vehicles per day), properties of the material being disturbed (e.g., moisture content), and climactic conditions (e.g., wind speed).

50. U. S. Environmental Protection Agency. Handbook: Remedial Action at Waste Disposal Sites (Revised) EPA/625/6-85/006. U. S. Environmental Protection Agency, HWERL, Cincinnati, OH. October 1985.

Useful for understanding remedial technologies, selecting potentially applicable technologies for a given waste site, and planning for remedial action. Contains sections discussing on-site and off-site disposal of wastes and soil, removal and containment of contaminated sediments, and in-situ treatments.

51. U. S. Environmental Protection Agency. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) — Air Emission Models (Draft Report). U. S. Environmental Protection Agency, OAQPS, Research Triangle Park, NC. April 1987.

Air emissions of volatile organic compounds from TSDFs (surface impoundments, wastewater treatment ponds, landtreatment, and landfills) are mathematically modeled. Model results are compared with measured site emissions.

52. U. S. Environmental Protection Agency. User's Guide for Emission Control Technologies and Emission Factors for Unpaved Road Fugitive Emissions. EPA/625/5-87-022. U. S. Environmental Protection Agency, AEERL, Research Triangle Park, NC, September 1987.

Explanation of factors, approach, use of factors, and control systems for unpaved road fugitive emissions, in more detail than the U. S. EPA's Compilation of Air Pollution Emission Factors (AP-42).

53. Vogel, G. A. Air Emission Control at Hazardous Waste Management Facilities. Journal of the Air Pollution Control Association, Volume 35, Number 5, May 1985.

Article covers several emission control methods that are applicable to five waste management facilities' emission sources: storage tanks, surface impoundments, landtreatment facilities, and landfills. Also includes cost ranges for each control method. It does not attempt to quantify emissions.

54. Wallace, Dennis D., A. R. Trenholm, and D. D. Lane. Assessment of Metal Emissions from Hazardous Waste Incinerators. Proceedings--78th APCA Annual Meeting, Detroit, MI. Published by APCA, Pittsburgh, PA. Pap 85-77. 1985.

MRI quantified emissions for specific metals at five incineration facilities. These emissions are expressed as a fraction of total particulate emissions and are not related to stack gas flow rates. Conclusions:

- Hazardous metals emissions for H.W. Incinerators are:

  Approximately equal to those for municipal solid waste units.
  2-20 times those for sewage sludge units.
  10-100 times those for coal-fired power plants.

- Control efficiencies for hazardous metals emissions achieved by wet scrubbers will probably be less than overall particulate control. This varies with specific metals.

55. Westbrook, W., E. Tatsch, L. Cottone, and H. Freeman. Field Testing of Pilot-Scale APCDs at a Hazardous Waste Incinerator. Proceedings of the 11th Annual Research Symposium on Incineration and Treatment of Hazardous Waste, Cincinnati, OH.

Three pilot-scale a.p.c.d.s were tested at a PCB incinerator facility. HCl and particulate control was evaluated. Control efficiencies for each are tabulated.

56. Wolbach, C. Dean. Prediction of Destruction Efficiencies. Environmental Progress, Volume 1, Number 1, pp. 38-41. February 1982.

Discusses a model for predicting destruction efficiencies. The model uses a destruction curve (time and temperature relationship required to achieve a certain destruction for a given compound) and a boiler curve (time and temperature relationship for the bulk gases in the unit). Using a graphical overlay method, the model determines whether there is sufficient time above a given temperature in the unit to achieve the required destruction.

APPENDIX B

SUPERFUND GLOSSARY OF TERMS

Administrative Order on Consent: A legal and enforceable agreement signed between EPA and potentially responsible parties whereby PRPs agree to perform or pay the cost of site cleanup. The agreement describes actions to be taken at a site and may be subject to a public comment period. Unlike a consent decree, an administrative order on consent does not have to be approved by a judge.

Administrative Record: All documents containing information the government uses to 1) select response actions, and 2) impose administrative sanctions for violations of CERCLA and Title III of SARA, the Emergency Planning and Community Right-to-Know Act. This paper trail includes the RI/FS, the Record of Decision, and public comments. SARA appears to limit judicial review of the adequacy of a response action to the administrative record (CERCLA Subsection 113(j)).

ARAR: A Federal standard, or State standard that is more stringent, is legally applicable to the substance, or relevant and appropriate under the circumstances, that the cleanup must at least achieve (CERCLA Subsection 121(d)).

Air Stripping: A treatment system that removes, or "strips," volatile organic compounds from contaminated ground water or surface water by forcing an airstream through the water and causing the compounds to evaporate.

Aquifer: An underground rock formation composed of materials such as sand, soil, or gravel that can store and supply ground water to wells and springs. Most aquifers used in the United States are within a thousand feet of the earth's surface.

Carcinogen: A substance that causes cancer.

Carbon Adsoprtion: A treatment system where contaminants are removed from ground water or surface water when the water is forced through tanks containing activated carbon, a specially treated material that attracts the contaminants.

Cleanup: Actions taken to deal with a release or threatened release of hazardous substances that could affect public health and/or the environment. The term "cleanup" is often used broadly to describe various response actions or phases of remedial responses such as the remedial investigation/feasibility study.

Comment Period: A time period during which the public can review and comment on various documents and EPA actions. For example, a comment period is provided when EPA proposes to add sites to the National Priorities List. Also, a minimum 3-week comment period is held to allow community members to review and comment on a draft feasibility study.

Community Relations: EPA's program to inform and involve the public in the Superfund process and respond to community concerns.

Comprehensive Environmental Response, Compensation, and Liability Act: A Federal law passed in 1980 and modified in 1986 by the Superfund Amendments and Reauthorization Act. The Acts created a special tax that goes into a Trust Fund, commonly known as Superfund, to investigate and clean up abandoned or uncontrolled hazardous waste sites. Under the program, EPA can either:

- Pay for site cleanup when parties responsible for the contamination cannot be located or are unwilling or unable to perform the work.
- Take legal action to force parties responsible for site contamination to clean up the site or pay back the Federal government for the cost of the cleanup.

Consent Decree: A legal document, approved and issued by a judge, that formalizes an agreement reached between EPA and potentially responsible parties (PRPs) where PRPs will perform all or part of a Superfund site cleanup. The consent decree describes actions that PRPs are required to perform and is subject to a public comment period. The decree must be filed with and approved by a court. Either a consent decree or an administrative order may be used in settlements about RI/FSs (CERCLA Subsection 122(d)).

Contract Lab Program: Laboratories under contract to EPA which analyze soil, water, and waste samples taken from areas at or near Superfund sites.

Cost-Effective Alternative: The cleanup alternative selected for a site on the National Priorities List based on technical feasibility, permanence, reliability, and cost. The selected alternative does not require EPA to choose the least expensive alternative. It requires that if there are several cleanup alternatives available that deal effectively with the problems at a site. EPA must choose the remedy on the basis of permanence, reliability, and cost.

Cost Recovery: A legal process where potentially responsible parties can be required to pay back the Federal government for money it spends on any cleanup actions.

De Minimis Settlement: A settlement EPA may reach with a PRP if EPA determines that either 1) both the amount and the toxic or hazardous effects of the substances the PRP contributed are minimal in comparison to other hazardous substances at the facility; or 2) the PRP is the owner of the facility, did not allow generation, transportation, storage, treatment, or disposal of any hazardous substance at the facility, did not contribute to the release or threat of release at the facility, and did not purchase the property knowing that it was used for the generation, transportation, storage, treatment, or disposal of any hazardous substances (CERCLA Subsection 122(g)).

Emergency Plan: Required under Title III of SARA, the Emergency Planning and Community Right-to-Know Act (Section 303(a)), for each emergency planning district. Local emergency planning committees (see also Local Emergency Planning Committees) will prepare the plans, which will include:

- Identification of facilities, and routes likely to be used for the transportation of extremely hazardous substances
- Methods and procedures for responding to any release of extremely hazardous substances
- Designation of community and facility emergency coordinators to help implement the plan
- Procedures providing reliable, effective, and timely notification
- Methods for determining the occurrence of a release, and the area or population likely to be affected by it
- A description of emergency equipment and facilities in the community and at each facility, and list of the persons responsible for such equipment and facilities
- Evacuation plans
- Training programs for local emergency response and medical personnel
- Methods and schedules for exercising the emergency plan.

Endangerment Assessment: A study conducted as a supplement to a remedial investigation to determine the nature and extent of contamination at a Superfund site and the risks posed to public health and/or the environment. EPA or State agencies conduct the study when legal action is pending to require potentially responsible parties to perform or pay for the site cleanup.

Enforcement: EPA's efforts, through legal action if necessary, to force potentially responsible parties to perform or pay for a Superfund site cleanup.

Enforcement Decision Document: A public document that explains EPA's selection of a cleanup alternative at a Superfund site through an EPA enforcement action. Similar to a Record of Decision.

Environmental Response Team: EPA hazardous waste experts who provide 24-hour technical assistance to EPA Regional Offices and States during all types of emergencies involving releases at hazardous waste sites and spills of hazardous substances.

Extremely Hazardous Substance: A substance on a list EPA published in November 1985 in Appendix A of the "Chemical Emergency Preparedness Program Interim Guidance," Title III Section 302(a). This list was also published in November 1986 (51 Federal Register 41,570) as an interim final rule under 40 CFR Part 300. EPA will revise the list from time to time.

Facility: Under CERCLA Subsection 101(9), 1) any building, structure, installation, equipment, pipe or pipeline (including any pipe into a sewer or publicly owned treatment works), well, pit, pond, lagoon, impoundment, ditch, landfill, storage container, motor vehicle, rolling stock, or aircraft; or 2) any site or area where a hazardous substance has been deposited, stored, disposed of or placed, or otherwise come to be located. Does not include any consumer product in consumer use or any vessel.

Facility Notification: Notice to EPA under CERCLA Subsection 103(c) of certain facilities where hazardous substances are or have been stored, treated, or disposed of. To provide a facility notification, you must complete and submit an EPA form identifying the facility; the amount and type of hazardous waste to be found there; and any known, suspected, or likely releases of such substances from the facility. Unless exempted (e.g., hazardous waste management facilities with permits or interim status under RCRA), an individual must file notice if the individual 1) presently owns/operates such a facility; 2) owned/operated such a facility at the time of disposal; or 3) accepted hazardous substances for transport and selected such a facility for treatment, storage, or disposal. Note that giving facility notification is different from reporting a specific release.

Ground Water: Water found beneath the earth's surface that fills pores between materials such as sand, soil, or gravel. In aquifers, ground water occurs in sufficient quantities that it can be used for drinking water, irrigation, and other purposes.

Hazard Ranking System: A scoring system used to evaluate potential relative risks to public health and the environment from releases or threatened releases of hazardous substances. EPA and States use the HRS to calculate a site score, from 0 to 100, based on the actual or potential release of hazardous substances from a site through air, surface water, or ground water to affect people. This score is the primary factor used to decide if a hazardous waste site should be placed on the National Priorities List.

Hazardous Chemical: Under Title III Section 311(e), any chemical which is a physical hazard or a health hazard, except:

- Any food, food additive, color additive, drug, or cosmetic regulated by the Food and Drug Administration
- Any substance present as a solid in any manufactured item to the extent exposure to the substance does not occur under normal conditions of use
- Any substance to the extent it is used for personal, family, or household purposes, or is present in the same form and concentration as a product packaged for distribution and use by the general public
- Any substance to the extent it is used in a research laboratory or a hospital or other medical facility under the direct supervision of a technically qualified individual

- Any substance to the extent it is used in routine agricultural operations or is a fertilizer held for sale by a retailer to the ultimate customer.

Hazardous Substance Superfund: The fund, largely financed by taxes on petroleum and chemicals, and a new "environmental tax" on corporations, that provides operating money for government-financed actions under CERCLA. The fund is a revolving fund in the sense that it enables the government to take action and then seek reimbursement later, or to clean up sites where responsible parties with sufficient cleanup funds cannot be found. Money recovered from PRPs is returned to the fund rather than to the U.S. Treasury.

Hazardous Substances: Under CERCLA Subsection 101(14), any element, compound, mixture, solution, or substance which, when released to the environment, may present substantial danger to public health/welfare or the environment. Also includes 1) any substance designated under Section 311(b)(2)(A) or any toxic pollutant listed under Section 307(a) of the Federal Water Pollution Control Act; 2) any hazardous waste having the characteristics identified under or listed pursuant to RCRA Subsection 3001 (excluding any waste suspended from regulation under the Solid Waste Disposal Act by Congress); 3) any hazardous air pollutant listed under Section 112 of the Clean Air Act; and 4) any imminently hazardous chemical substance or mixture for which the government has taken action under Section 7 of the Toxic Substances Control Act. Excludes petroleum (including crude oil not otherwise specifically listed or designated as a hazardous substance under any of the above laws), natural gas, natural gas liquids, liquified natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas). The definition in CERCLA is broader than the definition of hazardous wastes under RCRA.

Hazardous Wastes: Those wastes that are regulated or "listed" under RCRA (40 CFR Part 261) or wastes that are ignitable, corrosive, reactive, or toxic.

Hydrology: The science dealing with the properties, movement, and effects of water on the earth's surface, in the soil and rocks below, and in the atmosphere.

Incinceration: Burning of certain types of solid, liquid, or gaseous materials under controlled conditions to destroy hazardous waste.

Information Repository: A file containing current information, technical reports, and reference documents regarding a Superfund site. The information repository is usually located in a public building that is convenient for local residents--such as a public school, city hall, or library.

Leachate: A contaminated liquid resulting when water percolates, or trickles, through waste materials and collects components of those wastes. Leaching may occur at landfills and may result in hazardous substances entering soil, surface water, or ground water.

Local Emergency Planning Committee: Under Title III Section 301(c), a committee to include local and State officials; health, environmental, and transportation personnel; and industry representatives, among others, will be appointed by the State emergency response commission for each emergency planning district. The local committee will prepare an emergency plan for the district. (See also Emergency Plan and State Emergency Response Commission.)

Lead Agency: The Federal or State agency providing the On-Scene Coordinator (OSC) or the responsible official for a CERCLA response action. (See also On-Scene Coordinator.)

Mixed Funding Agreement: Allows EPA to reimburse parties for certain costs (with interest) of actions parties have agreed to perform, but EPA has agreed to finance. A mixed funding agreement can be used when some PRPs cannot currently pay for response costs, and other PRPs want to perform response action and be reimbursed for the nonparticipating PRPs' share (CERCLA Subsection 122(b)).

Monitoring Wells: Special wells drilled at specific locations on or off a hazardous waste site where ground water can be sampled at selected depths and studied to determine such things as the direction in which ground water flows and the types and amounts of contaminants present.

National Contingency Plan: The basic policy directive for Federal response actions under CERCLA (Subsection 105). It sets forth the Hazard Ranking System and procedures and standards for responding to releases of hazardous substances, pollutants, and contaminants. The plan is a regulation (40 CFR Part 300) subject to regular revision. (See also Hazard Ranking System.)

National Priorities List: A list of sites across the country slated for EPA enforcement action or cleanup (CERCLA Subsection 105). EPA intends to revise the NPL three times a year, in April, September, and December. SARA's schedules for EPA to evaluate sites are likely to cause sites to be added to the NPL. Note that many elements of the CERCLA/SARA program apply to sites regardless of whether they are on the NPL. (See also Hazard Ranking System.)

National Response Center: The national communications center for activities related to reponse actions. Individuals must notify the NRC if their facilities or vessels release hazardous substances (other than Federally permitted releases) in quantities considered reportable under CERCLA. Affected parties must notify NRC regardless of whether they have notified the appropriate State or local agency.

National Response Team: Representatives of 12 Federal agencies that coordinate Federal responses to nationally significant pollution incidents and provide advice and technical assistance to the responding agency(s).

Natural Resources: Land, fish, wildlife, biota, air, water, groundwater, drinking water supplies, and other such resources belonging to, managed by, held in trust by, or otherwise controlled by the U.S., any State or local government, any foreign government, or any Indian tribe (CERCLA Subsection 101(16)).

Nonbinding Preliminary Allocation of Responsibility: Determination EPA may make of each PRP's share of responsibility for cleanup. Part of SARA, the NBAR is an attempt to require EPA to provide more information to PRPs to encourage settlement (CERCLA Subsection 122).

Notice Letter: EPA's formal notice to PRPs that CERCLA-related action is to be undertaken at a site for which those PRPs are considered responsible. Notice letters are generally sent at least 60 days prior to scheduled obligation of funds for an RI/FS at a designated site. The intent is to give PRPs sufficient time to organize and to contact the government. A notice letter is sent again prior to implementing the remedy.

On-Scene Coordinator: An individual, designated within an EPA region, who directs Federal fund-financed reponse efforts and coordiantes all other Federal actions at the scene of a release. The OSC is responsible for developing contingency plans for Federal response in the OSC's area.

Operable Unit: A discrete response measure, consistent with a permanent remedy, but not the permanent remedy itself. Hence actions formerly considered initial remedial measures might now be preliminary operable units. The main thrust of operable units is to facilitate faster action at sites; for example, by encouraging responsible parties to take some action, without having to agree to an entire remediation effort all at once.

Parts Per Billion/Parts Per Million: Units commonly used to express low concentrations of contaminants. For example, 1 ounce of trichloroethylene (TCE) in 1 million ounces of water is 1 ppm: 1 ounce of TCE in 1 billion ounces of water is 1 ppb. If one drop of TCE is mixed in a competition-size swimming pool, the water will contain about 1 ppb of TCE.

Preliminary Assessment: The process of collecting and reviewing available information about a known or suspected hazardous waste site or release. EPA or States use this information to determine if the site requires further study. If further sutdy is needed, a site inspection is undertaken.

Potentially Responsible Parties: Those identified by EPA as potentially liable under CERCLA for cleanup costs. PRPs may include generators and present or former owners/operators of certain facilities or real property where hazardous wastes have been stored, treated, or disposed of, as well as those who accepted hazardous waste for transport and selected the facility.

Quality Assurance/Quality Control: A system of procedures, checks, audits, and corrective actions used to ensure that field work and laboratory analysis during the investigation and cleanup of Superfund sites meet established standards.

Reauthorization: The Superfund Amendments and Reauthorization Act (SARA) expanded the scope of CERCLA. Signed by the President on October 17, 1986, SARA is a 5-year extension of the program to clean up toxic releases at uncontrolled or abandoned hazardous waste sites.

Record of Decision: Written record deciding on the appropriate remedy selected for the cleanup at a site relying generally on the Remedial Investigation/ Feasibility Study (RI/FS). Published by the government after completion of an RI/FS, the ROD identifies the remedial alternative chosen for implementation at a Superfund site. The ROD is part of the administrative record. Judicial review of EPA cleanup decisions may be limited to the administrative record.

Regional Response Team: Representatives of Federal, State, and local agencies who may assist in coordination of activities at the request of the On-Scene Coordinator or Remedial Project Manager before and during response actions.

Release: Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (CERCLA Subsection 101(22)). Includes the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance, pollutant, or contaminant. Exclusions include 1) releases solely exposing workers in a work place, with respect to a claim they may bring against the employer; 2) engine exhaust emissions from motor vehicles, rolling stock, aircraft, vessels, or pipeline pumping station engines; 3) nuclear releases subject to the Atomic Energy Act and financial requirements of the Nuclear Regulatory Commission (also excludes any release of source, byproduct, or special nuclear material from any processing site designated under Section 102(a) or 302(a) of the Uranium Mill Tailings Radiation Control Act); and 4) the normal application of fertilizer. Release also means substantial threat of release.

Remedial Action: Under CERCLA Subsection 101(24), actions consistent with permanent remedy taken instead of, or in addition to, removal action to prevent or minimize the release or threat of release so that hazardous substances will not migrate to cause substantial danger to present/future public health, welfare, or the environment. Includes a variety of on-site measures (storage, perimeter protection, recycling or reuse, dredging, excavation, etc.), and required monitoring, and the costs of permanent relocation of affected populations when deemed necessary. Includes off-site measures such as transport, storage, treatment, destruction, or secure disposition of hazardous substances and associated contaminated materials.

Remedial Design: An engineering phase that follows the Record of Decision when technical drawings and specifications are developed for the subsequent remedial action at a site on the National Priorities List.

Remedial Investigation/Feasibility Study: Extensive technical studies conducted by the government or by PRPs to investigate the scope of contamination (RI) and determine the remedial alternatives (FS) which, consistent with the NCP, may be implemented at a Superfund site. Government-funded RI/FSs do not recommend a specific alternative for implementation. RI/FSs conducted by PRPs usually do recommend and technically support a remedial alternative. An RI/FS may include a variety of on- and off-site activities such as monitoring, sampling, and analysis.

Remedial Project Manager: An individual, designated within an EPA region, who directs Federal fund-financed remedial actions and coordinates all other Federal actions at the scene. The counterpart of the On-Scene Coordinator for removal actions. (See also On-Scene Coordinator.)

Remedial Response: A long-term action that stops or substantially reduces a release or threatened release of hazardous substances that is serious, but does not pose an immediate threat to public health and/or the environment.

Removal, Remove, or Removal Action: Under CERCLA Subsection 101(23), actions taken to respond promptly to an urgent need. With regard to hazardous substances, the cleanup or removal of released substances from the environment; actions in response to the threat of release; actions that may be necessary to monitor, assess, and evaluate the release or threat; disposal of removed material; or other actions needed to prevent, minimize, or mitigate damage to public health or welfare or to the environment. Removal also includes, without being limited to, security fencing or other measures to limit access; provision of alternative water supplies; temporary evacuation and housing of threatened individuals not otherwise provided for; and any emergency assistance provided under the Disaster Relief Act.

Reportable Quantity: Quantity of a hazardous substance considered reportable under CERCLA in the event of a release. Reportable quantities are identified in 40 CFR Subsection 302.5 and may be 1, 10, 100, 1000, or 5000 pounds. Quantities are to be measured over a 24-hour period.

Resource Conservation and Recovery Act: A Federal law that established a regulatory system to track hazardous substances from the time of generation to disposal. The law requires safe and secure procedures to be used in treating, transporting, sorting, and disposing of hazardous substances. RCRA is designed to prevent new, uncontrolled hazardous waste sites.

Response Action: A CERCLA-authorized action at a Superfund site involving either a short- term removal action or a long-term remedial response that may include, but it not limited to the following activities:

- Removing hazardous materials from a site to an EPA approved, licensed hazardous waste facility for treatment, containment, or destruction
- Containing the waste safely on-site to eliminate further problems
- Destroying or treating the waste on-site using incineration or other technologies
- Identifying and removing the source of ground-water contamination and halting further movement of the contaminants.

Responsiveness Summary: A summary of oral and/or written public comments received by EPA during a comment period on key EPA documents, and EPA's responses to those comments. The responsiveness summary is especially valuable during the Record of Decision phase at a site on the National Priorities List when it highlights community concerns for EPA decision-makers.

Risk Assessment: An evaluation performed as part of the remedial investigation to assess conditions at a Superfund site and determine the risk posed to public health and/or the environment.

Site Inspection: A technical phase that follows a preliminary assessment designed to collect more extensive information on a hazardous waste site. The information is used to score the site with the Hazard Ranking System to determine whether response action is needed.

State Emergency Response Commission: A commission State governors will appoint as required by Title III Section 301(a). The commission will appoint local emergency planning committees, supervise and coordinate their activities, and designate emergency planning districts.

Special Notice Procedures: The government may use these procedures under SARA's settlement provisions (Section 122) to attempt to reach agreement with PPRs to conduct RI/FS and other remedial actions. When it wants to begin such negotiations, the government must notify the PRP, and provide the following information: 1) names and addresses of other PRPs, 2) volume and nature of substances each PRP contributed, and 3) a ranking of the substances by volume.

Superfund: The common name used for the Comprehensive Environmental Response. Compensation, and Liability Act, also referred to as the Trust Fund.

Superfund Amendments and Reauthorization Act: Modifications to CERCLA enacted on October 17, 1986.

Surface Water: Bodies of water that are above ground, such as rivers, lakes, and streams.

Superfund Comprehensive Accomplishments Plan: Document EPA uses as a central planning and mangement tool for budgeting expenditures and technical support of enforcement actions at Superfund sites. The SCAP, maintained at Federal and regional EPA offices, indicates planned expenditures for Superfund sites on a quarter-by-quarter basis for each fiscal year.

Toxic Chemicals: Listed in Committee Print Number 99-169 of the Senate Committee on Environment and Public Works ("Toxic Chemicals Subject to Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986"). This list of 329 chemicals was published by EPA on February 4, 1987 (52 Federal RegisterI 3479). EPA may add or delete chcmicals from the list. In addition, Title III establishes a procedure citizens and governors can use to petition EPA to add or delete a chemical.

Treatment, Storage, and Disposal Facility: Any building, structure, or installation where a hazardous substance has been treated, stored, or disposed. TSD facilities are regulated by EPA and States under the Resource Conservation and Recovery Act.

Trust Fund: A Fund set up under the Comprehensive Environmental Response, Compensation, and Liability Act to help pay for cleanup of hazardous waste sites and to take legal action to force those responsible for the sites to clean them up.

Volatile Organic Compound: An organic (carbon-containing) compound that evaporates (volatilizes) readily at room temperature.

Water Purveyor: A public utility, mutual water company, county water district, or municipality that delivers drinking water to customers.

REFERENCES

1. Superfund Glossary, WH/FS-86-007 Winter 1986.
2. Superfund Handbook, ERT and Sidley and Austin Law offices.

APPENDIX C

ADVANTAGES AND DISADVANTAGES OF VARIOUS INCINERATION TECHNOLOGIES

TABLE C-1. ADVANTAGES AND DISADVANTAGES OF VARIOUS INCINERATION TECHNOLOGIES FOR SLUDGES AND HAZARDOUS MATERIALS DISPOSAL

Type	Design Features and Advantages	Limitations
Liquid Injection	Can be designed to burn a wide range of pumpable waste.	Limited to destruction of pumpable waste of viscosity of less than 20 stokes.
	Also used in conjunction with other incinerator systems as a secondary afterburner for combustion of volatiles.	Usually designed to burn specific waste streams.
	Hot refractory minimizes cool boundary layer at walls.	Smaller units can have problems with clogging of injection widely used design.
	HCl recovery possible.	
	No secondary combustion chamber is needed if the primary combustor has enough residence time--2 seconds as a general rule of thumb.	
	No continuous ash removal system is required other than for downstream air pollution control systems.	
	Capable of a fairly high turndown ratio.	
	Virtually no moving parts.	
	Low maintenance costs.	
Rotary Kilns	Can accommodate great variety of waste feeds: solids sludges. liquids, and some bulk waste contained in fiber drums.	Rotary kilns are expensive but have economy of scale.
		High capital cost for installation. because of the need for the secondary combustor.

(Continued)

TABLE C-1. (Continued)

Type	Design Features and Advantages	Limitations
Rotary Kilns (Cont.)	Rotation of combustion chamber enhances mixing of waste by exposing fresh surfaces for oxidation.	Spherical or cylindrical items may roll through kiln before complete combustion.
	Can maintain a high retention or residence time.	High particulate loadings.
	Continuous ash removal which does not interfere with the waste oxidation.	Problems in maintaining seals at either end of the kiln are a significant operating difficulty.
	The retention or residence time of the nonvolatile component can be controlled by adjusting the rotational speed.	Drying of aqueous sludge wastes or melting of some solid wastes can result in cylinder or ring formation on refractory walls.
	Rotary kilns can be operated at 1.400°C (2.550°F), making them well suited for the destruction of toxic compounds that are difficult to thermally degrade.	
Cement Kilns	Attractive for destruction of harder-to-burn waste, due to very high residence times, good mixing, and high temperatures.	Burning of chlorinated waste limited by operating requirements, and appears to increase particle generation.
	Alkaline environment neutralizes chlorine.	
Boilers (usually a liquid injection design)	Energy value recovery and fuel conservation.	Cool gas layer at walls result from heat removal. This constrains design to high-efficiency combustion within the flame zone.
	Availability on sites of waste generators reduces spill risks during hauling.	

(Continued)

TABLE C-1. (Continued)

Type	Design Features and Advantages	Limitations
Boilers (Cont.)		Nozzle maintenance and waste feed stability can be critical.
		Where HCl is recovered, high temperatures must be avoided.
Multiple Hearth	Passage of waste onto progressively hotter hearths can provide for long residence times for sludges.	Tiered hearths usually have some relatively cold spots which inhibit even and complete combustion.
	Able to handle wide variety of sludges.	Opportunity for some gas to short circuit and escape without adequate residence time.
	Large quantities of wastebound water can be evaporated.	Not suitable for wastestreams which produce fusible ash when combusted.
	Can utilize many types of fuels including coal dust, waste oils and solvents.	Units have high maintenance requirements due to moving parts in high-temperature zone.
	Fuel burners can be added to any of the hearths to maintain a desired temperature profile.	Need a secondary combustor. Solid wastes generally require pretreatment.
	For multizone configuration hearths, fuel efficiency is high and improves with the number of hearths used.	
Fluidized-bed Incinerators	Turbulence of bed enhances uniform heat transfer and combustion of waste	Potentially high particulate loading.

(Continued)

TABLE C-1. (Continued)

Type	Design Features and Advantages	Limitations
Fluidized-bed Incineration (Cont.)	Mass of bed is large relative to the mass of injected waste. Large economy of scale.	
At-Sea Incineration	Minimum scrubbing of exhaust gases required by regulations on assumption that ocean water provides sufficient neutralization and dilution. This could provide economic advantages over land-based incineration methods. Also, incineration occurs away from human populations. Shipboard incinerators have greater combustion rates.	Not suitable for waste that are shock sensitive, capable of spontaneous combustion, or chemically or thermally unstable due to the extra handling and hazard of shipboard environment.
Pyrolysis	Air pollution control needs minimum: air-starved combustion avoids volatilization of any inorganic compounds. These and heavy metals go into insoluble solid char. Potentially high capacity.	Some wastes produce a tar which is hard to dispose of. Potentially high fuel maintenance costs.
Molten Salt	Molten salts act as catalysts and efficient heat transfer medium. Self-sustaining for some wastes. Reduces energy use and reduces maintenance costs.	Commercial-scale applications face potential problems with regeneration or disposal of ash-contaminated salt. Not suitable for high ash wastes.

(Continued)

TABLE C-1. (Continued)

Type	Design Features and Advantages	Limitations
Molten Salt (Cont.)	Units are compact; potentially portable.	Chamber corrosion can be a problem.
	Minimal air pollution control needs; some combustion products, e.g., ash and acidic gases are retained in the melt	
High-Temperature Fluid Wall	Waste is efficiently destroyed as it passes through cylinder and is exposed to radiant heat temperatures of about 2,200°C (4,000°F).	Core diameters and cylinder length limit throughout capacity.
	Cylinder is electrically heated; heat is transferred to waste through inert gas blanket, which protects cylinder wall.	Scale-up may be difficult due to thermal stress on core.
	Mobile units possible.	Potentially high costs for electrical heating.
Plasma Arc	Very high energy radiation breaks chemical bonds directly, without series of chemical reactions.	Limited throughput. High use of NaOH for scrubbers.
	Simple operation, very low energy costs, mobile units planned.	
Wet Oxidation	Applicable to aqueous waste too dilute for incineration and too toxic for biological treatment.	Not applicable to highly chloroinated organics, and some wastes need further treatment.
	Lower temperatures requried, and energy released by some wastes can produce self-sustaining reaction.	Used as pretreatment to biological wastewater treatment.

TABLE C-1. (Continued)

Type	Design Features and Advantages	Limitations
Wet Oxidation (Cont.)	No air emissions.	
Super Critical Water	Applicable to chlorinated aqueous waste which are too dilute to incinerate. Takes advantage of excellent solvent properties of water above critical point for organic compounds. Injected oxygen decomposes smaller organic molecules to CO_2 and water. No air emissions.	Probable high economy of scale. Energy needs may increase on scale-up.

Sources: References (Cheremisinoff 1986) and (Lee 1986).

APPENDIX D

DESCRIPTION OF PROTOCOL FOR ESTIMATING EMISSIONS AND ASSESSING AIR QUALITY IMPACTS

APPENDIX D

DESCRIPTION OF PROTOCOL FOR ESTIMATING EMISSIONS AND ASSESSING AIR QUALITY IMPACTS

This appendix presents a step-by-step protocol for estimating emissions from a variety of remedial operations during the clean-up of Superfund (NPL) sites. The protocol is designed to allow the user to make relative comparisons of the impacts on air quality from remedial options being considered for implementation. The protocol is graphically presented and each step of the process is discussed. The mathematical equations and calculations common to assessments of air quality impacts for all remediation options are then presented. Equations and input values for each specific remediation option considered in this project may be found in Section 3 of the main body of the manual.

D.1 DISCUSSION OF PROTOCOL STEPS

A flow chart showing the steps of the protocol is given as Figure D-1. Each step is discussed below.

D.1.1 Step 1 - Define Air Pathway Analysis (APA) Objectives

Performance of an air pathway analysis for remediation may be useful during the Feasibility Study (FS), Remedial Design (RD), Record of Decision (ROD) or Remedial Action (RA) phase of a Superfund project; and is most critical during the RD phase. However, the objectives of the APA will vary depending on the phase of the project. In general, the objectives of the APA are to assess the impact on downwind receptors from the implementation of a given remedial technology at a given operating rate. Therefore, the first protocol step is to clearly define what objectives are to be met for a given APA. The intended uses of the analysis results dictate the type, quantity,

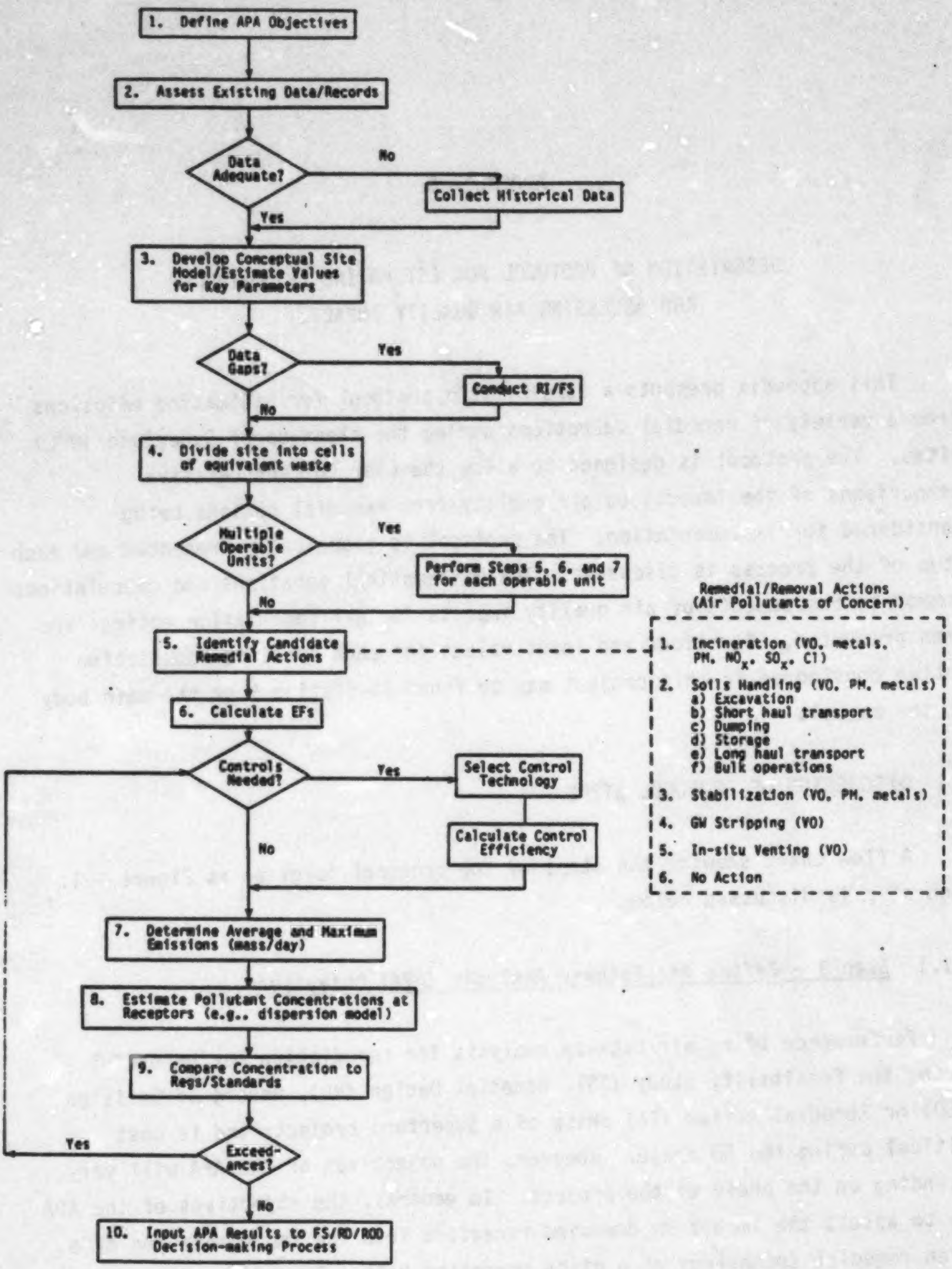

1. Define APA Objectives
2. Assess Existing Data/Records
Data Adequate?
No
Collect Historical Data
Yes
3. Develop Conceptual Site Model/Estimate Values for Key Parameters
Data Gaps?
Yes
Conduct RI/FS
No
4. Divide site into cells of equivalent waste
Multiple Operable Units?
Yes
Perform Steps 5, 6, and 7 for each operable unit
No
5. Identify Candidate Remedial Actions
6. Calculate EFs
Controls Needed?
Yes
Select Control Technology
Calculate Control Efficiency
No
7. Determine Average and Maximum Emissions (mass/day)
8. Estimate Pollutant Concentrations at Receptors (e.g., dispersion model)
9. Compare Concentration to Regs/Standards
Exceed-ances?
Yes
No
10. Input APA Results to FS/RD/ROD Decision-making Process
Remedial/Removal Actions (Air Pollutants of Concern)
1. Incineration (VO, metals, PM, NO$_x$, SO$_x$, Cl)
2. Soils Handling (VO, PM, metals)
a) Excavation
b) Short haul transport
c) Dumping
d) Storage
e) Long haul transport
f) Bulk operations
3. Stabilization (VO, PM, metals)
4. GW Stripping (VO)
5. In-situ Venting (VO)
6. No Action

Figure D-1. Flow chart of air pathway analysis for remediation.

and required confidence level of the input data to the APA. In general, as the Superfund process for a given NPL site advances, more details are available for input to the APA, but more specific and more accurate outputs are required.

The following steps are recommended:

- Recognize the stated CERCLA objective to characterize the nature and extent of contamination including the air contamination pathway.

- Review the characteristics of the site and surrounding area, then formulate site-specific objective(s). Consider:

    - -- Technical feasibility;
    - -- Program resources;
    - -- Community involvement;
    - -- Bioreceptor location;
    - -- Waste characteristics;
    - -- Disposition of wastes;
    - -- Other factors.

- Circulate the stated site-specific objectives for review and modify as necessary.

D.1.2 Step 2 - Assess Existing Data and Records

At the point where remedial options and their associated air quality impacts are being evaluated, extensive information about the site should already have been collected as part of the initial steps of the Remedial Investigation/Feasibility Study (RI/FS) process. Site files should be examined to determine if adequate quantity and quality of data are available. Historical information may be obtained from EPA enforcement and technical files, USGS and SCS files, state and local regulatory agency files, files of the potentially responsible parties (PRPs), personal interviews, etc. See Section 2.0 of Reference D-1 for further information regarding potential data sources. A site inspection(s) should also have been performed to confirm and update the historical information, as well as to conduct a preliminary assessment of health and safety concerns for both on-site workers and the surrounding community. In many cases, a remedial investigation (RI) will also have been performed to characterize the site. The field investigations typically involve collecting a series of surface and subsurface solid and liquid samples, making limited air quality measurements and screening the samples using a phased analytical approach. Detailed information on site characterization has been published by the EPA (D-2).

The existing data should be reviewed and the adequacy of the data assessed. The user should be acquainted with the steps of this protocol and the required inputs to the various emission factor equations (see Table D-3) prior to evaluating the existing data set. The data review will typically involve a systematic search of the site files to identify and record all pertinent information for the APA for remediation. Not all necessary inputs to the protocol may be available in the site files; further historical data collection from primary sources may be required. Under certain circumstances, an APA may need to be performed despite existing data gaps. Therefore, the equations in this protocol for estimating emissions contain default inputs, i.e., typical values to use for a given parameter when no site-specific information is available. However, site-specific information is always preferable and should be used whenever possible.

The available data will rarely all be intrinsically equal in quality; it is therefore necessary to assess the adequacy of the data. Major considerations include:

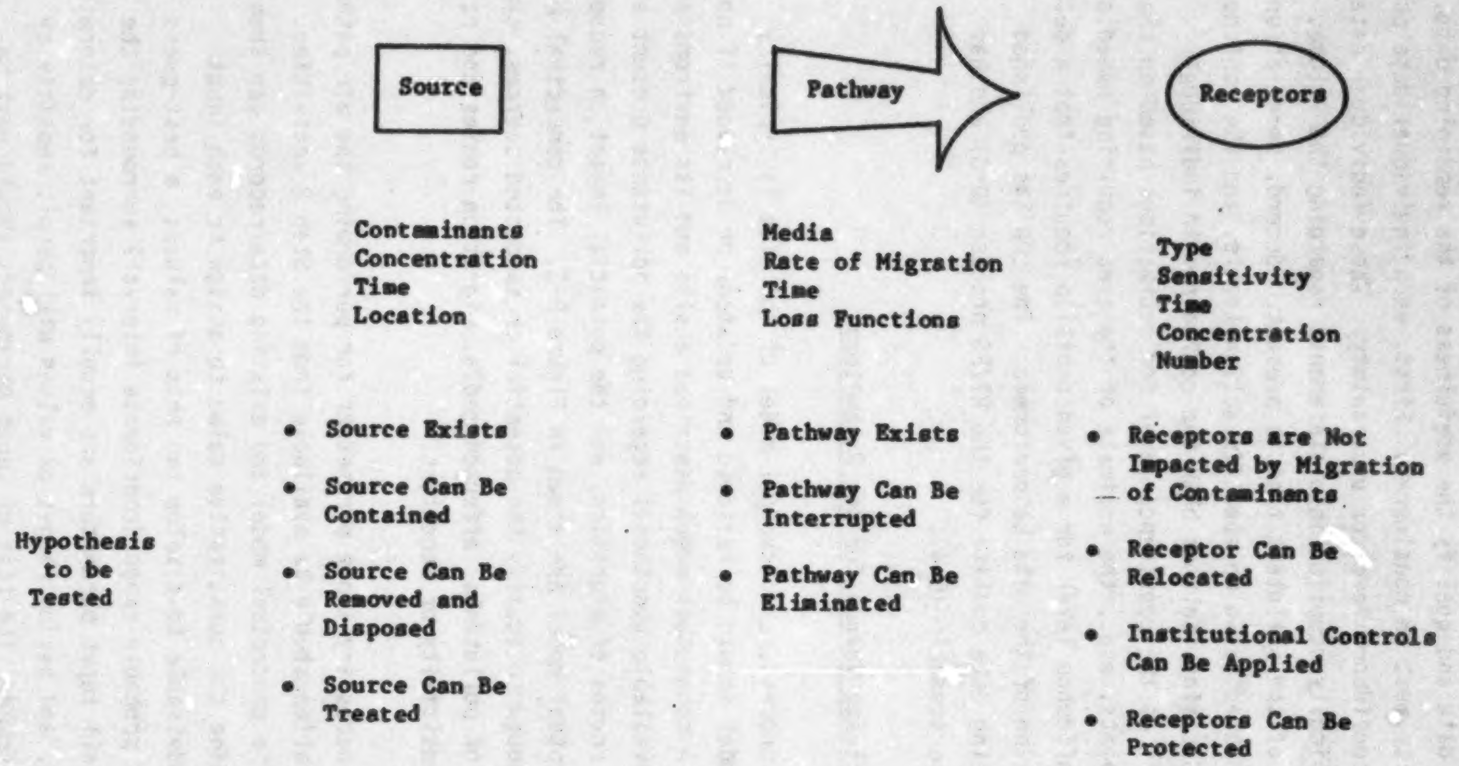
- Age of the data;
- Sampling and analytical procedures used;
- Analytical detection limits; and
- QA/QC procedures and documentation.

The uncertainty associated with each data measurement must be known to evaluate the existing data set. The data validation process should identify and delete invalid data and qualify the usefulness of the remaining data. Two types of data quality must be considered. First, each individual data point has an associated confidence level or uncertainty. These individual data points are then typically compiled into statements regarding the volume, type, distribution, etc. of the pollutant that is present. Second, remediation decisions are delineated based on specific action levels, and the confidence level for a given decision includes both the confidence in individual measurements as well as the confidence level for estimations based on the individual measurements, e.g., the estimate of the area requiring remediation. Determining the confidence level for a given decision requires that a detailed statistical evaluation of the data be performed. The EPA has published guidance for assessing data quality for the RI/FS process (D-3) and has published an example scenario (D-4).

D.1.3 Step 3 - Estimate Values for Key Parameters

During the RI process, a conceptual model of the site is typically developed. This model should be reviewed and updated, or developed if none currently exists. A conceptual model describes a site and its environs and presents the best available hypotheses regarding the pollutants present at the site, the possible routes of migration, and the potential impact on receptors. Elements of a conceptual model are shown in Figure D-2. The conceptual model must be detailed enough to qualify the potential or suspected sources, types, and concentrations of pollutants, affected media, migration routes and rates, and location and sensitivity of receptors.

A list of all necessary input parameters for performing the air pathway analysis for remediation should be available from the Step 2 activities described above. The conceptual model and existing data/records can then be consulted to determine the quantitative value to assign to each input parameter. It is advisable to develop two sets of values: a best-guess single value, and a probable range (confidence interval) surrounding the single value. Not all input parameters are equally important for determining air quality impacts, and having ranges of values will permit sensitivity analyses to be performed. The list of input parameters should next be



	Source	Pathway	Receptors
	Contaminants Concentration Time Location	Media Rate of Migration Time Loss Functions	Type Sensitivity Time Concentration Number
Hypothesis to be Tested	• Source Exists • Source Can Be Contained • Source Can Be Removed and Disposed • Source Can Be Treated	• Pathway Exists • Pathway Can Be Interrupted • Pathway Can Be Eliminated	• Receptors are Not Impacted by Migration of Contaminants • Receptor Can Be Relocated • Institutional Controls Can Be Applied • Receptors Can Be Protected

Figure D-2. Elements of a conceptual evaluation model (D-3).

evaluated. If significant data gaps exist (e.g., waste type, volume, or distribution) or the data quality is unacceptable, then a site investigation may be necessary to procure the required data. As stated earlier, this protocol includes default inputs for use when further data collection is not cost effective.

D.1.4 Step 4 - Divide Site into Equivalent Units

NPL sites containing mixed wastes or having other types of inherent variability may require separate remedial options to be considered for each equivalent area. The site should be theoretically divided into units of equivalent waste for evaluating remedial options. For example, a hypothetical site mitigation may involve the clean-up of buried wastes, contaminated ground water, and sludge pits. This hypothetical site would thus have at least three distinct units and perhaps more. If the type, concentration, or distribution of a given form of contamination varies widely, then further subdivision of the units should be considered. Similarly, if the soil media (soil type, porosity, contaminant level, etc.) varies significantly either laterally or with depth, or the proximity of receptors varies significantly across the site, then further subdivisions of the units may be necessary.

The air quality impacts from remediation of each unit should be evaluated using Steps 5 and 6 of this protocol. An iterative process may be necessary to identify the most efficient method(s) from an air emissions standpoint of treating a contaminated site (i.e., it may require several attempts to make the most appropriate selection of waste cells, remedial options, and control technologies).

D.1.5 Step 5 - Identify Candidate Remedial Actions

A large number of possible technologies are available for remediating NPL sites. The generic technology groups addressed in this protocol were listed in Figure D-1. These are thought to represent the most commonly used and the most viable of the available options. However, new remedial options are undergoing rapid research and development (e.g., biodegradation), and new technologies should be considered once their effectiveness has been demonstrated and sufficient information is available to develop emission factors for them.

The best options for treating a given site are, of course, site specific. The EPA recommends that the following be assessed during development of the conceptual model to determine the appropriate remedial and/or removal actions at a site (D-3):

- Population, environmental, and welfare concerns at risk;
- Routes of exposure;
- Spatial distribution of contaminants;
- Atmospheric dispersion potential and proximity of targets;
- Amount, concentration, hazardous properties, environmental fate and form of the substance(s) present;
- Hydrogeological factors;
- Climate;
- Extent to which the source can be adequately identified and characterized;
- Potential for reuse, recycling, or treatment of substances at the site;
- Likelihood of future releases if the substances remain on site;
- Extent to which natural or man-made barriers currently contain the substances and the adequacy of the barriers;

- Assessment of the potential pathways of migration and a model of such;

- Extent to which the substances have migrated or are expected to migrate from their source and whether migration poses a threat to public health, welfare, or the environment; and

- Extent to which contamination levels exceed applicable or relevant and appropriate federal or state requirements (ARARs) relating to public health or environmental standard and criteria.

When selecting one or more remedial options to consider for a given situation, the primary evaluation criterion should be the short- and long-term effect of the option on the health and safety of on-site workers and surrounding receptors.

In most cases, the viable remedial options can be limited to two or three options per waste cell. Further guidance for selecting remedial options is present in Sections 2 and 3 of this protocol under the discussions of the specific technologies. This protocol assists in evaluating these options in terms of their impact on air quality; other considerations also apply as indicated in the discussion of Step 10.

D.1.6 Step 6 - Calculate Emission Factors

For each unit and remedial option, the appropriate emission factor should be determined. Specific calculation steps for each remedial activity are outlined beginning in Section 3.3.

D.1.7 Step 7 - Determine Average and Maximum Emissions

The emission factors from the previous step are given in terms of mass of pollutants per unit operation or per given time frame. Emissions during several time frames may be of concern including:

1) Maximum emissions during any 15-minute period;
2) Maximum emissions during any 60-minute period;
3) Average emissions during an 8-hour work period;
4) Average emissions during a 24-hour period;
5) Total emissions during remediation; and
6) Average post clean-up emissions during a 24-hour period.

To determine average, maximum, or overall emissions, follow the steps given below.

First, select the time frame of interest from the above list.

Second, convert all emission factors into mass per unit time using Equation D-1 and values listed in Table D-1. In some cases, separate emission factor equations are available for a given remedial activity for calculating peak and average EF_i values.

$$\text{Operable Unit 1:} \quad XEF_{i,t} = (XEF_{i,uo})(CF) \qquad \text{(D-1)}$$

where: $XEF_{i,t}$ = emission factor for species i during remedial option X (mass/time);

$XEF_{i,uo}$ = emission factor for species i during remedial option X (mass/unit operation); and

CF = conversion factor from Table D-1 (unit operation/time).

Equation D-1 will provide maximum and average emissions from a given operable unit for a given remedial option directly, if the appropriate operating frequency/conversion factor are selected. If multiple remedial options are practiced in the same in the same time frame, then the contributions from each option must be summed using Equation D-2.

$$\text{Operable Unit 1:} \quad XEF_{i,t} + YEF_{i,t} + ZEF_{i,t} \ldots \qquad \text{(D-2)}$$

TABLE D-1. CONVERSION FACTORS FOR CALCULATING TIME-BASED EMISSION FACTORS FOR NON-CONTINUOUS PROCESSES

Remedial Option	Emission Factor Units	Typical Operation Frequency[a]	Conversion Factor: Maximum Emissions	Conversion Factor: Average Emissions
Incineration	kg/hr			
	kg/kg of feed			
	kg/m^3 off-gas	125 m^3/min	1875 m^3/15 min	60.000 m^3/8hr
Air Stripping	g/min	3.500 L/min	52.500 L/15 min	5.04x10^6 L/day
In-situ Venting	g/min	0.5 m^3/min	7.5 m^3/15 min	720 m^3/day
Soils Handling - VOC				
Excavation	kg/ton[b]	50 ton/hr 8 hr/day	50 tons/hr	400 ton/day
Dumping	kg/ton[c]	8 ton/load 1 load/5 min 5 loads/hr	1.6 ton/5 min 8 ton/60 min	- -
		8 ton/load 5 load/hr 8 hr/day	- -	40 ton/hr 320 ton/day
Soils Handling - Particulates		(see Section 3.6.1.8)		

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[a] Substitute site-specific frequency, if known.

[b] Assume 1 m^3 = 1.000 kg, average scoop = 4 m^3.

[c] Assume 1 m^3 = 1.000 kg, average scoop = 8 m^3.

where: X = remedial option X;
Y = remedial option Y; and
Z = remedial option Z.

Third, for total emissions from a given unit during remediation, use Equation D-3 and output of Equation D-1.

$$\text{Operable Unit 1:} \quad E_i = (XEF_{i,t})(t_x) + (YEF_{i,t})(t_y) \ldots \qquad \text{(D-3)}$$

where: E_i = total emissions during remediation for species i (kg);
$XEF_{i,t}$ = average emissions for species i during remedial option X (kg/day); and
t_x = number of days remedial option X is performed.

Fourth, if multiple units exist, then emissions for the entire site can be determined by inputting the results of Equations D-1, D-2, or D-3 as required into Equation D-4. For summing the contributions of multiple units using Equation D-1 or D-2 outputs, the time dependence of the remedial activities must be taken into account. The maximum emissions for different units may not coincide, or remedial activities may not take place in all the units during a given time frame.

$$\text{Site Emissions} = \text{Unit 1 Emissions} + \text{Unit 2 Emissions} + \ldots \qquad \text{(D-4)}$$

D.1.8 Step 8 - Estimate Pollutant Concentrations at Receptors

The emission factors provide an emission rate per unit time or unit operation. It is usually necessary to convert this emission rate to a concentration at the receptors of interest, in order to assess health and safety concerns arising from air quality impacts. The most valid means to accomplish this is to use the emission factor as a source term (input) to an atmospheric dispersion model. The models recommended by the EPA (49) are listed in Table D-2. PC-compatible versions of some of the dispersion models

TABLE D-2. RECOMMENDED AIR QUALITY (DISPERSION) MODELS

Buoyant Line and Point Source Dispersion Model (BLP)

Caline 3

Climatological Dispersion Model (CDM 2.0)

Gaussian-Plume Multiple Source Air Quality Algorithm (RAM)

Industrial Source Complex Model (ISC)

Multipoint Point Gaussian Dispersion Algorithm with Terrain Adjustment (MPTER)

Single Source (CRSTER) Model

Urban Airshed Model (UAM)

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are readily available. For urban or industrial areas, the ISC model is an appropriate choice. Both long-term and short-term versions are available. Dispersion modeling is discussed in more detail in Volume IV (3).

In addition to a source term, the models generally require information regarding:

- Size and geometry of source;
- Location and profile of adjacent structures;
- Wind speed;
- Wind variability;
- Temperature;
- Dispersion coefficients;
- Atmospheric stability;
- Receptors; and
- Particle size distribution.

The models are typically independent of the chemical and physical properties of the pollutant (though the actual rate of dispersion is dependent on the molecular weight of the pollutant). Therefore, the models need to be run only once per given set of meteorological conditions and receptors, and the downwind concentrations can then be ratioed to various source terms. In some cases, contributions from background sources must also be considered.

For particulate matter, the same dispersion models listed in Table D-2 can be used. The model should include a settling velocity term or other factor to account for gravitational effects on the particles. The potential distance a particle may drift before being deposited is affected by the starting height of the particle, its terminal settling velocity, and the degree of atmospheric turbulence. Predictive models have been developed that use particle diameter and mean wind speed as the key inputs (50). Particles with diameters greater than 30 um generally settle out within a short distance.

The downwind concentrations determined from the dispersion modeling should be compared to any existing downwind ambient air data collected during trial or pilot-scale remediation activities, as a check of the modeling results. Obviously, the predicted downwind concentrations for full-scale remediation should exceed measured downwind concentrations during limited remediation activities or those at baseline conditions. If not, the model inputs should be re-examined and background sources of contamination assessed.

D.1.9 Step 9 - Compare Concentration at Receptors to Applicable Regulations/Standards

The modeling results should be compared to established action levels to determine if the site emissions pose a potential health or safety risk. The results may also be used as input to long-term risk assessment work. If exceedances are noted, then three options are available:

- Re-evaluate the control technologies to be used during remediation;
- Re-evaluate the selected remedial options and their operating rates; or
- Increase the level of personal protective clothing worn by site workers (if they are the only receptors affected by the exceedance).

Action levels will vary depending on the location of the NPL site and the proximity and orientation of sensitive receptors. A number of health standards exist and the applicable regulatory agency may select some fraction of an existing health standard to serve as an action level (i.e., a trigger point where steps are taken to reduce the exposure of sensitive receptors). Information sources for air standards are available (D-5,D-6,D-7,D-8, and D-9).

Emissions of certain compounds pose an odor problem at levels below the point of health and safety concerns. This is particularly true for organic compounds that contain sulfur (e.g., thiophenes and mercaptans). Odor threshold values can be obtained from ACGIH's Threshold Limit Values publication, the TOXNET computerized database, or other sources. The odor potential of remediation should be evaluated for sites: 1) with past histories of odor complaints, 2) having nearby receptors, or 3) containing contaminants likely to produce odorous compounds. In general, the control technologies discussed for each remedial option will reduce odorous emissions commensurate with reductions in total emissions. However, in some cases, complete odor control is not possible and education of the impacted public as to the risks/benefits of remediation is imperative.

D.1.10 Step 10 - Input Air Pathway Analysis Results to Record of Decision Process

This protocol is intended for use in evaluating the air pathway transport mechanism during remediation. The results of the APA should be one of many factors that are considered when preparing Feasibility Studies, Remedial Designs, and Record of Decisions. The overall ROD process must consider myriad other site-specific factors, both objective and subjective, including: ground-water and surface water pathways, existing exposure/ contact hazards, long-term risk assessments, overall cost effectiveness of remedial alternatives, site hazard ranking, etc.

APPENDIX D: REFERENCES

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D-6. Chemical Rubber Company. Handbook of Chemistry and Physics. 55th Edition, Robert Weast Ed., pp. D-85-86. CRC Press. 1974.

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D-8. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment and Biological Exposure Indices with Intended Changes for 1985-86. American Conference of Governmental Industrial Hygienists, 6500 Glenway Avenue, Building D-5, Cincinnati, Ohio, 45211. 1985.

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